Design and Evaluation of
Digital Activating Learning Materials
for Food Chemistry Education

Promotoren

Prof. dr. ir. H. Gruppen
Persoonlijk hoogleraar bij de leerstoelgroep Levensmiddelenchemie

Prof. dr. ir. A.G.J. Voragen
Hoogleraar in de Levensmiddelenchemie

Co-promotoren

Drs. R. Hartog
Programmamanager instructietechnologie voor het onderwijsinstituut

Promotiecommissie

Prof. dr. R. Amadò
Institute Food Science and Nutrition, Zurich, Zwitserland

Prof. dr. E.W. Brascamp
Wageningen Universiteit

Prof. dr. P.A. Kirschner
Open Universiteit, Heerlen

Prof. dr. L.H. Skibsted
The Royal Veterinary and Agricultural University, Frederiksberg, Denemarken

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Design and Evaluation of Digital Activating Learning Materials for Food Chemistry Education

Julia Diederen

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Abstract

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The research described in this thesis is a design oriented research that aims at designing and developing activating digital learning materials for food chemistry education. It is expected that digital activating learning materials will provide an efficient and motivating situation for both teachers and students. The learning materials described in this thesis were designed and developed with the help of design guidelines and aimed at satisfying preset design requirements. Both the guidelines and requirements were articulated specifically for these learning materials during the design processes. They were based on the viewpoints of three different fields: subject matter (food chemistry), education, and information and communication technology (ICT). The field of food chemistry and the education of food chemistry are both described in detail. An overview of educational principles for the design of activating learning materials is given. Furthermore, the possibilities of the use of ICT within education are highlighted. The design, development and subsequently implementation and evaluation of the following digital activating learning materials is described in detail in this thesis:

- *exercises* - to support students extensively in acquiring the required knowledge level.
- *assignments on quantitative aspects* - to support students in acquiring quantitative problem solving skills in relation to the field of food chemistry
- *assignments on research experiments* - to support students in learning how to design experiments: what options they have in analysing food and how to make choices between these options.

The way interaction between the students and the computer can be varied, the specific use of the various types of support, and the highly visual presentation are regarded as the three most important properties of the digital activating learning materials described in this thesis. Furthermore, to design activating digital learning material, the use of both generic and specific guidelines was noticed to be an important property of the design process. It can be concluded that the digital activating learning materials improved the education in food chemistry. In each evaluation a positive appreciation of the students of the learning materials was noticed. Teachers can now easily provide any student with activating learning materials. The digital learning materials serve as a proof of feasibility of the design oriented research. Therefore, the design processes of these learning materials also serve as examples of *how* digital learning materials can be developed.

Contents

Chapter 1 - General Introduction

In order to learn, people need to be active. Therefore, in education one has to find ways to activate students in a meaningful sense. A way to activate students is by providing them activating digital learning materials. The research described in this thesis aims at designing and developing activating digital learning materials for food chemistry education.

It is proposed that the design of digital learning materials should be based on three fields: the field of the subject matter (food chemistry), the field of education and the field of information and communication technology (ICT). In this introduction these three fields are introduced, including a detailed description of the courses Food Chemistry and Advanced Food Chemistry at Wageningen University. These are the courses for which the learning materials described in this thesis have been designed, developed and evaluated. This introductory chapter is concluded with an approach for the design and evaluation of activating digital learning materials.

FOOD CHEMISTRY

All foods are of biological origin, such as plants, animals, and bacteria. So, the field of food chemistry is not only based on (bio)(organic) chemistry, but also on the discipline of biology. Also the discipline physics is needed to understand the processes, the quality and structure of food products (Hultin, 1997). The field of food chemistry is, therefore, often regarded as a cross-section of several disciplines, of which chemistry, biology and physics are the main ones (Hultin, 1997).

The following definitions of food chemistry have been given by different authors:

- Food chemistry deals with the composition and properties of food and the chemical changes it undergoes during handling, processing and storage (Fennema, 1996).
- Food chemistry is the science that treats the composition, properties, and structure of substances in food and of the transformations they undergo during processing and storage (Hultin, 1997).
- Food chemistry is the competent discipline for investigating the composition, structure and properties of unprocessed and processed foodstuffs and their components, for elucidating their chemical and biochemical changes and for analysing essential and undesirable compounds, thereby protecting and enhancing public health and food quality (Ruiter and Thier, 1997).
- Food chemistry is a systematic evaluation and understanding of water, carbohydrates, lipids, proteins, minerals and vitamins as they undergo chemical interaction/reaction during the harvest, processing, storage and distribution of foods (Christen and Smith, 2000).
- Food chemistry is involved not only in elucidating the composition of the raw materials and end-products, but also with the changes which occur in food during its production, processing, storage and cooking (Belitz *et al.*, 2004).

The similarities between these five definitions of food chemistry relate to the composition of food, the (bio) chemical reactions and how these reactions change the food components, and the effect of treatments (processing, storage, and handling) on food and food components. Also, three of the above mentioned definitions explicitly mention the properties and structure of food components. Although processing is mentioned in each definition, the discipline process engineering is not part of the field of food chemistry, since food chemistry is only interested in the *effects* of processing on foods (Hultin, 1997).

Another way to characterise food chemistry and to obtain an overview of which subjects are in general regarded as food chemistry is by analysing the content of textbooks on food chemistry. For this, six textbooks on food chemistry (Belitz *et al.*, 2004; Christen and Smith, 2000; Coultate, 2002; deMan, 1999; Fennema, 1996; Wong, 1989) have been analysed for 'the purpose of the book' (educational purpose or as a reference for researchers), 'the content of the chapters', 'number of pages per chapter' and 'the order of the chapters'. An overview is given in Table 1.1.

The similarity between the textbooks with respect to the above mentioned characteristics is high. Each book relates its main chapters to the major and minor components in food. Four out of six textbooks start with a chapter on water (after an introduction or preface, if present). The subject water as the first subject is probably related to the idea that water is the major component of many foods. Water influences the structure, appearance, and taste of foods and their susceptibility to spoilage (Fennema, 1996). The chapter on water is most often followed by three chapters on the major food components carbohydrates, lipid and proteins (the order for these three subjects is different among the textbooks). These three chapters are followed by five chapters on the most important minor food components enzymes, vitamins, minerals, colorants and flavours or aromas. The order of these five chapters is different between the six books. Most books finalize the information on minor components with two chapters on additives and contaminants or toxicants, respectively. These are components that are not naturally present (in desired amounts) in the food product. Three textbooks have chapters on specific food raw materials and food products as milk, eggs, meat and vegetables. Furthermore, five out of six textbooks have one or two chapters on additional subjects such as sweeteners and food biochemistry.

The overview of the six textbooks in Table 1.1 shows that many food chemists perceive food chemistry from the point of view of the components in food. As was seen above, even some food chemists define food chemistry from the viewpoint of components (Christen and Smith, 2000). When only looking at the chapters on the major components (water, carbohydrates, lipids and proteins) and the chapters on the minor components (enzymes, vitamins, minerals, colorants, flavours/aroma, additives and contaminants), it becomes clear that the ratio of the total pages devoted to the major components to the total pages spent on the minor components is on average 0.96 (with a standard deviation of 0.20).

Table 1.1: Overview of the content of 6 textbooks related to food chemistry.

textbook / characteristic	**Wong**	**Coultate**	**Christen & Smith**	**deMan**	**Belitz, Grosch & Schieberle**	**Fennema**
title of the textbook	Mechanism and Theory in Food Chemistry	Food: The Chemistry of its Components	Food Chemistry: Principles and Applications	Principles of Food Chemistry	Food Chemistry	Food Chemistry
year of edition (edition)	1989	2002 (4th)	2000	1999 (3rd)	2004 (3rd)	1996 (3rd)
main focus (general means structure, properties, and reactions)	general and specific to molecular mechanisms of reactions	general and each chapter relates to food products	general	general	general	general
purpose	-education -reference	-reference (-education)	-education	-education	-education -reference	-education -reference
total number of pages	374	408	421	491	988	1072
Chapters	**Presence or absence of chapter** (v = present, - = absent)					
preface/introduction	-	v	v	v	-	v
% of total$		1	1	<1		1
water	-	v	v	v	v	v
carbohydrates	v	v	v	v	v	v
lipids	v	v	v	v	v	v
proteins/peptides/amino acids	v	v	v	v	v	v
(chapters)	1-3*	1-4, 11	1-8	1-4	1,2,4,5	1, 3-5
% of total$	39	46	33	43	29	32
enzymes	v	-	v	v	v	v
vitamins	v	v	v	v	v	v
minerals	-	v	v	v	v	v
colorants	v	v	v	v	-	v
flavours/aroma	v	v	v	v	v	v
additives	v	v	v	v	v	v
contaminants/toxicants	v	v	v	v	v	v
(chapters)	4-6, 8-10	5-10	9-13, 15,16	5-7, 9-11	3, 6-10	6-12
% of total$	57	53	28	45	24	37
raw material food products#	-	-	v	-	v	v
% of total$			34		49	19
texture/dispersed systems	-	-	-	v	-	v
sweeteners	v	-	-	-	-	-
food quality/shelf- life	-	-	-	-	-	v
food biochemistry	-	-	v	-	-	-
regulatory control	-	-	-	v	-	-
% of total$	5		3	12		9

*: The numbers represent the order in which the chapters appear in each book.
$: the % of total amount of pages for this group of chapters.
#: Food products as titles in these books are often milk, eggs, meat, vegetables, etc.
v: present, -: absent

Furthermore, the content of the chapters is also quite equal. All give attention to chemical structures, chemical reactions, physico-chemical properties, influence of conditions, and quality aspects in view of the components.

None of the books pay specific attention to the analysis of food or food components, probably because the analytic techniques used within food chemistry change rapidly. Specific books exist for the analysis of food. For example, the book *Food Analysis* by Nielsen (Nielsen, 1998) focuses solely on analytical techniques used within food chemistry and is primarily intended for undergraduate students majoring in Food Science and Technology. Or the book *Food Analysis: Theory and Practice* by Pomeranz and Meloan (Pomeranz and Meloan, 2000), which is a textbook for students in Food Science and Technology, as well as a reference and a source book on analytical methods and instruments for researchers in the field of food analysis. Also, dedicated books for specific analyses exist, such as books related to the analysis of one food component (e.g. proteins, dietary fibre) or related to the use of one specific technique (e.g. use of chromatography techniques within food). The diversity of the different books and their content show that the number of techniques used within food chemistry is large.

When focussing on the two most comprehensive textbooks of food chemistry via a comparison of the three editions of Fennema (Fennema, 1976, Fennema, 1985, Fennema, 1996), an extension of the subject matter from 776 to 938 and finally to 1072 pages can be seen. Although most chapters have increased in the number of pages, it are especially the subjects water (from 3.5 to 7%) and vitamins and minerals (from 5 to 11%) that have increased substantially. Remarkable, the subject carbohydrates decreased in attention (from 12 to 6%), as well as the chapters on food products (from 24 to 19%).

Also, the three English editions of Belitz and Grosch (and Schieberle) (Belitz and Grosch, 1987; Belitz and Grosch, 1999; Belitz *et al.*, 2004), show an extension of the subject matter from 720 to 920 and finally to 988 pages. These textbooks show no change in the ratio of the number of pages between the chapters and no change in the classification of the chapters. Both the textbooks of Fennema and of Belitz and Grosch (and Schieberle) show mainly additions to their contents from one edition to the other, and only minor changes in the already existing content. The development of the editions of both textbooks show that the most important change in the field of food chemistry is the increase in the amount of subject matter.

From the definitions and the textbooks described above, the following specific characteristics of the field of food chemistry can be deduced:

- Food chemistry is dealing with food systems, which are heterogeneous in nature, containing many different components, with many different types of possible reactions and many different kinds of properties. The research within food chemistry is, therefore, also heterogeneous, and deal with many influences and many exceptions.

- Food chemistry is dealing with the effects of processing, harvesting, and storage on for example nutritional quality, sensory quality, and shelf life.
- Research within food chemistry applies many different kinds of techniques to analyse the different components and their properties.

FOOD CHEMISTRY EDUCATION

The subject food chemistry is probably always part of curricula of education in Food Science, Food Technology or Food Science and Technology. Besides these curricula food chemistry is often also a part of the curricula of Human Nutrition, Food Biotechnology, Agricultural Engineering, or of Chemical Engineering.

According to Munck and co workers (Munck *et al.*, 1998) Food Science and Technology "is drawing on a wealth of disciplines from chemistry and physics, mathematics and statistics, to biology, genetics, medicine, microbiology, agriculture, process engineering and environmental science, and even further to the cognitive sciences like sensory and consumer analysis and psychology as well as to other social disciplines like economy". Any curriculum in Food Science and Technology should, therefore, have a multidisciplinary approach. At Wageningen University, the curriculum Food Science and Technology has as main subjects (1) the chemistry of the food components and chemical reactions occurring in food, (2) the physical stability of food, and (3) the microbiology of food that is made by fermentation or spoiled by unwanted growth of micro-organisms (food safety). But also, (4) the production of food structures, (5) the biology of food and its raw materials, (6) the nutritional aspects, (7) the sensorial aspects (taste, smell, appearance, and mouth feel), (8) consumer behaviour and (9) the economical aspects are subjects of the curriculum. The courses within the curriculum are related to seven main disciplines: Chemistry, Physics, (Micro) Biology, Process engineering, Human Nutrition, Mathematics/Statistics, and Economy/Business management. Many courses have aspects of more than one discipline.

Food Chemistry courses

Worldwide, many universities offer a course named Food Chemistry or courses named Food and Flavour Chemistry, Food Chemistry and Quality, etc. These courses have rather similar learning objectives, although each university chooses her own focus of the course. This depends, for example, on the research focus of the department or laboratory that teaches the course and on the food raw materials produced in the country or area.

Also, many universities teach courses *related to* food chemistry. It is beyond the introduction of this thesis to list and discuss all these different courses and explain their use. To give an idea of how food chemistry is related to various courses, the situation at the Wageningen University will be explained.

With respect to food chemistry, the courses provided by Wageningen University range from courses in which food chemistry is treated integrally, with the emphasis predominately on the field food chemistry as defined earlier, to courses in which food chemistry is integrated with specific subjects, as depicted in Table 1.2. The lower the course is ranked in Table 1.2, the more the course treats food chemistry as an *integrated* part of that course, which means that food chemistry itself is less and less treated *integrally*. Besides the courses mentioned in Table 1.2, Wageningen University provides product-oriented courses, such as dairy science and meat science.

The courses Food Chemistry and Advanced Food Chemistry

As explained before, the courses Food Chemistry and Advanced Food Chemistry are both integral courses that deal with food chemistry as a whole. Food Chemistry, the introduction course for second year Bachelors students, focuses its attention on knowledge and competences necessary to *recognise* typical situations related to food chemistry. The course Advanced Food Chemistry focuses on knowledge and competences necessary for *explaining* and *investigating* situations related to food chemistry. Table 1.3 lists the main learning objectives for both courses. These learning objectives are articulated by the staff of the Laboratory of Food Chemistry and match the goals of the curriculum Food Science and Technology at Wageningen University. The goals of this curriculum are compiled in participation with future employers of the students Food Science and Technology.

Table 1.2: Courses at Wageningen University in which food chemistry plays an important role.

type	course	focuses on food chemistry integrated with
increasingly integrated with other subjects ↓	Food Chemistry	-
	Advanced Food Chemistry	-
	Food Enzymology	enzymology / biochemistry
	Food and Ingredient Functionality	food physics
	(Advanced) Food Fermentation	food microbiology
	Sensory research	sensory sciences
	Food Processing and Product Functionality	food processing, sensorial analysis
	Mathematical concepts for Food Technology	mathematics / food processing
	Nutritional Aspects of Foods	human nutrition
	Food related allergies and intolerances	human nutrition
	Product and Process design	amongst others food processing, physics, microbiology, and consumer behaviour.

Science education

According to Hodson (Hodson, 1992) the main goals of science education, provided by universities, are:

- *learning the scientific content* : "acquiring and developing conceptual and theoretical knowledge"
- *learning the scientific methodologies* : "developing an understanding of the nature and methods of science and an awareness of the complex interactions between science and society"
- *learning the scientific activities* : "engaging in and developing expertise in scientific inquiry and problem solving"

The goal *learning the scientific content* is often supported by supplying readers and/or books, giving lectures and by providing activities, such as exercises, in which students can process the concepts and theories. The goals *learning the scientific methodologies* and *learning the scientific activities* are often supported by scheduling practical activities (e.g. laboratory classes or fieldwork).

Table 1.3: Main learning objectives for the courses Food Chemistry and Advanced Food Chemistry.

course Food Chemistry	course Advanced Food Chemistry
• Recognising the molecular structure of the most common food components • Being able to recognise and explain the generic functional and chemical properties of the most common food components • Being aware of the influence of the conditions on the properties of food components • Recognise the, for food important, chemical and biochemical reactions • Know which and how reactive groups of food components play an important role in (bio) chemical reactions • Know the effect of (bio)chemical reactions on the characteristics of food in a qualitative sense • Being aware of the influence of the environment and (process) conditions on the (bio)chemical reactions in food • Being able to translate qualitative effects into quantitative judgements • Knowing the, for food analysis, most common analytical methods and techniques • Being able to choose analytical methods to analyse food compounds • Being able to *conduct* experiments and to analyse and interpret the results of these experiments	• Have an extended knowledge of the structure and properties of components and of (bio)chemical reactions in food. • Being able to explain the influence of conditions on (bio)chemical reactions • Being able to explain the influence of conditions on the properties of food components • Being able to explain the mechanisms during processing and storage which cause modifications of the components in food • Being able to explain the mechanisms during processing and storage which cause the formation of certain components in food • Being able to explain the mechanisms by which other components in food influence the behaviour and reactivity of the key components in food • Have knowledge about the difference in composition and behaviour of components in a number of foods • Being able to *design* and conduct experiments and to analyse and interpret the results of these experiments.

In Table 1.4 an overview is given of the incorporation of the three main goals of science education in the two courses Food Chemistry and Advanced Food Chemistry. The course Food Chemistry is related to the more generic chemical components, reactions and situations in food. It gives a descriptive overview of the field of food chemistry. In this course students also learn to use the standard techniques within food chemistry, based on analytical questions and students learn to make choices between these techniques. Furthermore, students learn to critically analyse and evaluate data gained from their experiments or from fictitious situations.

In the course Advanced Food Chemistry more attention is paid to the specific structure, properties, reactions and situations related to the chemical components in food than in the course Food Chemistry. The course content has an explanatory nature, but students also learn how to apply a research method and to write a more article-like report. The activities that students perform in the laboratory classes are related to a research question, which makes that they have to choose themselves which analysis they will need.

Table 1.4: Comparison of the courses Food Chemistry and Advanced Food Chemistry for the three purposes of science education.

course	learning of the scientific content	learning of the scientific methodologies	learning of the scientific activities
Food Chemistry	• food components o generic structure o generic properties o generic reactions o generic situations • singular problems • overview of the field • descriptive	• learn to make choices between techniques • critical analysis of data	• using standard common techniques and methods • activities based on analytical questions
Advanced Food Chemistry	• food components o specific structure o specific properties o specific reactions o specific situations • complex problems • exceptions in the field • explanatory	• apply a research method, with hypothesis and design of experiments • critical analysis of data • write an article-like report	• using more specific, state of the art techniques • activities based on research question

Characteristics of Food Chemistry education

Education in any field has its own specific characteristics. For food chemistry education several characteristics can be mentioned. Below, three characteristics are mentioned that receive special attention within this thesis.

Heterogeneous knowledge

As explained above, food chemistry is dealing with food systems, which are heterogeneous in their components, reactions and properties. Therefore, the knowledge and understanding that students need to gain are also quite heterogeneous. This gives students sometimes a that they need to learn an overwhelming amount of facts.

Reducing the heterogeneity or the amount of the knowledge that students need to acquire in the food chemistry courses is not an option. A food technologist should be able to solve problems: (s)he is confronted with a (practical) problem and is searching for a solution by using scientific methods and theories and aims at process and product development and assurance and improvement of quality. Voss (Voss, 1989) explains that a good problem solver is a flexible user of knowledge in the field of the problem. To solve a problem well one should have a substantial basis of knowledge in combination with skills to use this knowledge in various contexts of the problems. Therefore, an expert in the field of the problem is better in defining, and thereby solving a problem, than a beginner in the field.

Consequently, food chemistry education should support students in acquiring the required level of knowledge of food chemistry.

Diverse research methods

Within the heterogeneity of the field of food chemistry, students have to learn experimental methods for analysing different kinds of components. Therefore, within food chemistry, research methods from several research areas are used, such as for protein research, carbohydrate research, lipid research, enzymatic research, flavour research, and sensory research. Students need to learn to make choices between the methods available within each research area for the different components, taking care of the restrictions that are often induced by the other components present in food raw materials or food products.

Food chemistry education should support students in learning what options they have in analysing food and how to make choices between these options to design experiments.

Combining qualitative and quantitative approaches

Food chemistry is often considered as a quite qualitative field of science. For example, it is explained how a treatment modifies a component. This is usually accompanied by qualitative statements on the effects of internal and external factors on the extent or rate of the modification, e.g. the higher the temperature, the faster the brown colouring. To translate these qualitative statements into more quantitative statements, food technologists use quantitative models: for example, models on chemical kinetics (reaction orders, activation energy, Arrhenius constant), on chemical equilibrium, and on shelf life (D-value, Z-value, Q_{10}). Being able to use these models in solving problems, which could be called quantitative problem solving skills, is important for the food technologist to be able to make predictions, to make estimations, to choose between possible solutions for a problem, to calculate costs or benefits, etc. With these skills a technologist can, for example, determine the yield of an isolation, plan experiments, optimise food production processes, predict food losses, predict shelf life, and specify and quantify the desired amount of a functional ingredient, enzyme or chemical.

Food chemistry education should support students in acquiring quantitative problem solving skills in relation to the field of food chemistry.

To ensure that students acquire the skills and knowledge related to the characteristics mentioned above, specific educational activities are needed. These activities should:

- support students extensively in acquiring the required knowledge level
- support students in learning what options they have in analysing food and how to make choices between these options to design experiments
- support students in acquiring quantitative problem solving skills in relation to the field of food chemistry

ACTIVATING LEARNING MATERIALS

Learning by being active

To support students in learning one needs to provide students with carefully designed learning activities. Physically, learning means a change in the brain: the brain has a capacity to reorganize in response to an experience. So, the brain is different before and after learning. Educationally, it is accepted that learning has taken place or is taking place when an intended change in behaviour can be measured or noticed (Anderson, 1995). An intended change in behaviour means for example that someone is able to explain the difference in molecular structure between amylose and amylopectin after learning while (s)he could not explain this before.

If learning means a change in the brain of a person, it means that (intended) learning can only take place when the learner makes an effort: a mental or physical activity. This means that education is only effective when the learner is provoked to commit an activity. The most effective way to provoke a person to the intended activity is by explicitly motivating the person to perform this activity.

This brings us to one of the foundations of the research described in this thesis: in order to support students in learning, one needs to provide them with the learning activities that explicitly provoke them to commit the intended (needed) mental or physical activities.

Learning resources

Within education activities can be supported with many different resources. The choice between the different resources depends on the situation. It is not within the scope of this thesis to discuss all possible resources. Therefore, two resources that are often used in education are compared: the teacher and learning materials. A teacher can ask questions, give assignments verbally, give feedback or give an explanation, make drawings on the blackboard, tell the students what to read, can point, direct, focus, emphasize, etcetera. The advantages of a teacher as a learning resource are, for example, that a teacher is flexible, can focus his/her attention to any possible situation, and can have social interactions, such as influencing the group dynamics. The disadvantages of a teacher are, for example, that (s)he can only be at one place at one time, can only give specific feedback to one student or a small group of students at a time, and that the quality of the teaching can fluctuate drastically from teacher to teacher and from day to day. The advantages of learning materials are that they always give the same information, can be reused many times, can be used at different places at the same time and any time, give the possibility to cope with many students at one time and can be used to supply students with structured self-study activities. The main disadvantage of learning materials is that they are less flexible in coping with specific situations than a teacher.

Educational principles

To design and develop efficient and effective activating learning materials, the following educational principles are regarded as important: principles with respect to motivation, cognitive load, and support.

The learning material should contain motivating elements

Motivation is regarded essential to learning (Hull, 1940). There should be a motivational element in the learning material to provoke the performance of an (mental or physical) activity. This motivational element can be of several natures. The following research findings show the importance of motivation and what motivates students (Pintrich, 2003):

- Students perform better when they expect to do well.
- Students are likely to do well when they believe they feel in control of their own learning.
- Students are motivated when they are interested (intrinsic motivation).
- Students are motivated when they think the task is important.
- Students can feel motivated in relation to academic goals, but also in relation to social goals.

Pintrich (Pintrich, 2003) listed several design principles to design motivating education, of which a few are mentioned here:

- Provide clear and accurate feedback.
- Provide opportunities to be successful, to challenge students.
- Provide opportunities for students to apply choice and control.
- Provide stimulating and interesting tasks, including novelty and variety in activities.
- Provide tasks that are relevant and useful to students.

Keller (Keller 1983) established a model on motivation of students: the ARCS model. This model identifies four essential components for motivating instruction. The four components are:

- Attention: arouse and sustain curiosity and interest.
- Relevance: make a connection to students' needs, interest, and motives.
- Confidence: help students to develop a positive expectation for successful achievement.
- Satisfaction: provide extrinsic and intrinsic reinforcement for effort.

The learning material should prevent cognitive overload

The cognitive load theory assumes that people have a limited capacity of working memory and a very large long-term memory (Sweller *et al.*, 1998; Kirschner, 2002). Cognitive load refers to the load imposed on working memory at an instance in time. Cognitive load may be affected by the intrinsic nature of the learning material, by the manner in which the learning material is presented, and the activities required from the student (Bannert, 2002; Kirschner, 2002; Sweller *et al.*, 1998). When cognitive load is high due to for example a bad user interface design of the learning material, less cognitive capacity is available for learning. Important ways to reduce cognitive load are (Kester *et al.*, 2001; Mayer and Moreno, 2002; Mayer and Moreno, 2003):

- Pre-training: provide instruction of the components present in the learning material.
- Adequate sequencing of information or segmenting: divide the subject matter into bite-size elements and allow some time between successive elements.
- Weeding: eliminate extraneous material to make the information concise and coherent.
- Multiple representation principle: present an explanation both textually and visually.
- Integrated presentation: place text that is describing an element of a visual, next to this element.
- Signalling: provide clues to the learner about how to select and organize the materials (e.g. highlight key-words).

- Just-in-time information presentation: provide information precisely at the time it is needed to carry out a task, which can be supportive information (before a task) or prerequisite information (during a task).

The learning material should contain supporting elements

Support during an educational activity is important to make sure that an activity becomes an effective and efficient *learning* activity (Collis *et al.*, 2001, Moreno and Mayer, 2005). Students can be supported in several ways: feedback, hints, and (just in time) access to information. The following types of support are regarded as important:

- Explanatory feedback: react on the outcome of the activity of the student by explaining the reason why a certain answer is correct or incorrect, or by explaining the usefulness of the activity.
- Corrective feedback: react on the outcome of the activity of the student by telling whether an answer is correct. Solely corrective feedback is not as effective as explanatory feedback. The combination of corrective and explanatory is regarded as more effective than corrective feedback alone. (Moreno and Mayer, 2005)
- Hint: tell the student how (s)he could act in completing the assignment. Hints can be used to make sure that students do not get stuck. A hint is providing clues.
- Access to information: depending on the (amount of active) prior knowledge of the student, some students need more information than others to be able to accomplish the task of the activity. By giving access to this information the students can guide themselves. Although this information should be accessible all the time, it is of importance that students also have access to the information just in time. This means that at the moment a student could need some extra information, direct access is provided to this information (e.g. by indicating at which page more information is available or by giving a hyperlink to this information in the case of digital learning material).

USING ICT FOR ACTIVATING LEARNING MATERIALS

The use of ICT within higher education

The existence of a journals such as 'Computers & Education' since 1976 shows that already for about 30 years teachers and educational designers are searching for and have found useful ways to incorporate computer technologies into education. The existence of the internet has highly increased the possibilities of communication between computers. Information and communication technology (ICT) is the technology that makes this communication possible.

Nowadays, there is a wide range of possibilities for using computer technologies in higher education (Figure 1.1). Computer technologies can be used for 1) facilitating purposes for students (*computer assisted facilities*), for example registration for exams, library access, and study schedules, and for 2) learning, which is often called *computer assisted learning*. Within computer assisted learning, one can make use of *computer programs* (e.g. a spreadsheet program), of specific *learning materials / objects* (especially designed for education), and from *communication facilities*.

When using ICT within computer assisted learning, a distinction exists between using ICT to develop and distribute learning material (for individual learning) and using ICT for communication between students and between students and teachers (for collaborative learning) (Trentin, 2002). Also, a combination exists in which ICT is used to deliver learning material with which students work in a collaborative sense by using communication facilities. An example is that all students work on the same digital assignment, while students can have electronic communication to ask each other questions.

The use of ICT to develop and distribute learning materials is functional for amongst others:

- easy distribution to many computers for simultaneous use (as opposed to non-digital learning materials, such as overhead-sheets and a textbook, which can only exist in one place at a time).
- easy keeping up-to-date of or making changes in the learning material.
- restricting use for enrolled persons (authorisation).
- database communication (for example remembering the answers of students).

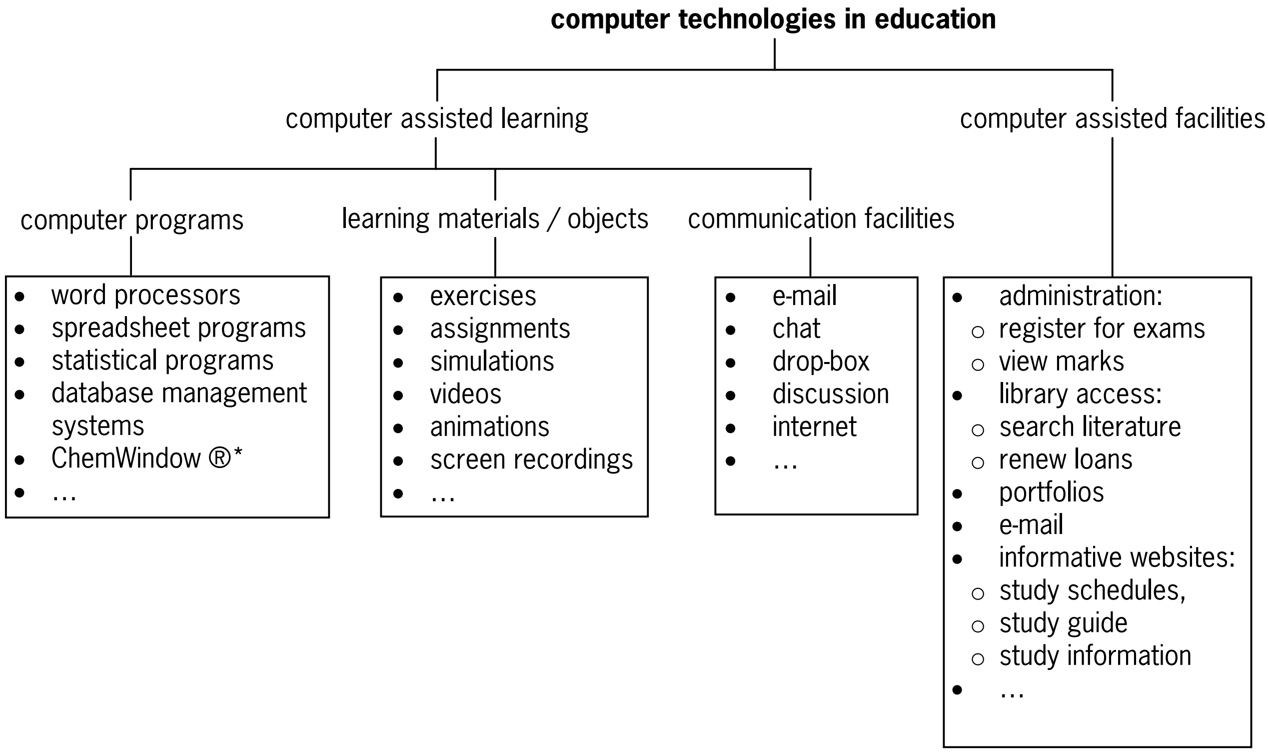

Figure 1.1: A schematic overview of the role of computers in higher education.
(* ChemWindow is a program with which someone can draw molecular structures.)

Communication between students via computers, by using for example chat, e-mail, and video-conference, can be used for online education (distance education in which interaction among participants is generated by online communication) or for mixed education or blended learning (a mix of face-to-face (onsite) education and online education) (Knezek *et al.*, 2000; Trentin, 2002). A different way of using ICT is for electronic field trips, in which students have the opportunity to visit locations while having access to digital information, by using mobile communication technology (Wentzel *et al.*, 2005).

Types of digital learning materials or learning objects

Learning materials or learning objects can be defined as content objects meaningfully presented to accomplish specific objectives related to learning. Additionally, they are designed using a conceptual framework embedded within instructional theory, strategies, and methodology (Martinez, 2002). Furthermore, digital learning objects are generally understood to be digital entities deliverable via the internet.

Wiley (Wiley, 2002) proposes a taxonomy for learning objects based on several properties, of which the properties *granularity* and *function* will be explained in more detail below.

Learning objects can be classified according to their *granularity* : from single-topic objects to entire courses (Collis and Strijker, 2003). Digital courses are a composition of several learning objects. Wiley (Wiley, 2002) proposes the metaphor of atoms, to explain the granularity of learning objects. In this metaphor, learning objects are atoms that can be interlinked to form a meaningful molecule: a course or module. In fact, a learning object itself can be built up of smaller parts, just like an atom is built up of protons, electrons and neutrons, which themselves are made of even smaller parts. Figure 1.2 shows the distinction between *single* topic objects on the left side and *complete* digital courses or modules on the right side.

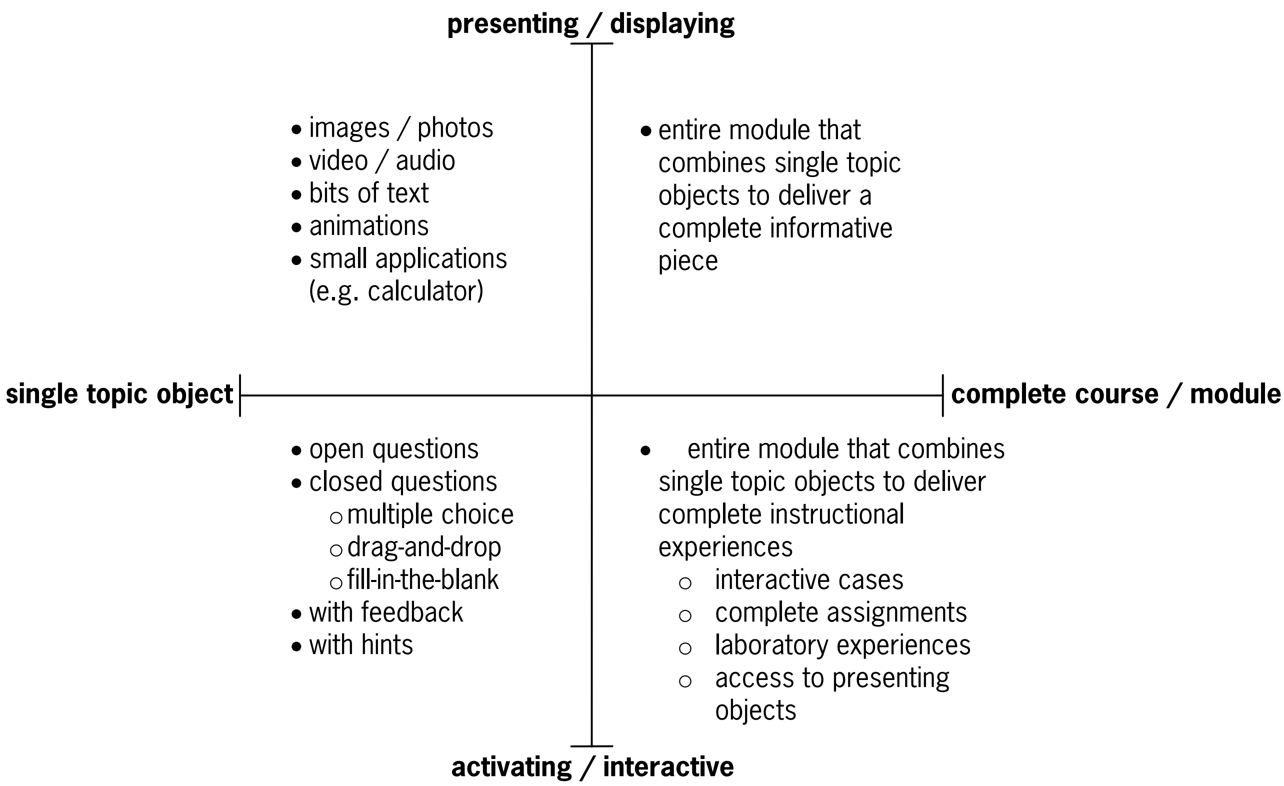

Figure 1.2: Division of learning objects in granularity (single or complete) and in function (presenting or activating).

Learning objects can also be classified according to their *function* (Figure 1.2): from pure presenting or displaying information to activating objects by using interaction between students and the computer. *Activating* learning objects are often presenting parts with an additional activating part. For example, a question is often combined with an image or some text. The difference from a purely *presentational* object is that the student needs to do something with the information given by the presentational parts (by using the mouse or the keyboard).

When combining granularity and function a figure as shown in Figure 1.2 can be drawn. This figure shows presenting single topic objects of the left side of the vertical line, complete courses/modules on the right side of this line, presenting learning objects above the horizontal line and activating learning objects beneath this line.

Using animations within activating learning materials

Activating digital learning materials can be defined as complete digital modules consisting of a logical combination of both presenting and activating single topic objects. Within digital learning materials animations are popular learning objects. Animations are often attractive and give a feeling of professionalism to the learning material.

A computer animation is a series of rapidly changing pictures of objects that are drawn or created, which gives an illusion of motion on the computer screen. There have to be at least fifteen pictures per second for a fluent and continuous motion. Animations are different from video in the sense that an animation consists of objects that are drawn or created, while video shows real objects.

Animations can be very powerful for learning if applied and designed carefully (Lewalter, 2003; Rieber and Kini, 1991; Narayanan and Hegarty, 2002). Animation can be included for cosmetic, attention gaining, or motivating purposes, but also for presenting and clarifying purposes.

There are two disadvantages in using animation as learning objects. First, the development of animations are in general more time-consuming than static objects, because animations need more pictures than static visuals and because not only the static components, but also the various stages of the moving and changing components have to be drawn or created. Second, animations used for cosmetic, attention gaining, or motivating purposes probably do not enhance learning and can even distract students (Weiss *et al.*, 2002).

The choice between different types of learning objects for the presentation of subject matter should be based on the less expensive (for the university) and the most cognitive efficient (for the student) object (Clark, 1994). Since developing animations is time-consuming (expensive) and animations are not always cognitive efficient, it is useful to know how to decide when the use of an animation as learning object could be useful.

Decision model for use of animations

To make a decision or to analyse whether an animation is useful, so whether an animation will contribute to learning or not, decision models can be used. Weiss and co-workers (Weiss *et al.*, 2002) proposed a decision model that deals, amongst others, with the purpose of the animation and the nature of the subject matter. This model can be extended to a model including decision questions on the learning objectives and the effect on cognitive load. This decision model (Figure 1.3) consists of the following steps:

- *Dividing subject matter into separate units* : The subject matter of the intended learning object is divided into topics, sub-topics and finally, into logical, small parts, called units.
- *Classifying the units* : To determine whether it is useful to make an animation of a unit, the first step is to classify these units. The units can be classified into facts, rules, principles, concepts and procedures (Weiss *et al.*, 2002). In Table 1.5 a definition and an example of each class are given.
- *Deciding usefulness of animation* : Procedures and concepts are considered to be qualified for animation, while facts, principles and rules are not (Weiss *et al.*, 2002). Animations have potential for communicating concepts and procedures which involve changes over time because of its ability to represent motion (Rieber and Kini, 1991). Not only change in time, but also a certain direction of the path of travel of an object, its trajectory, can be visualised effectively with animation (Rieber and Kini, 1991). Furthermore, also systems not visible to the naked eye have a great potential for (clarifying) animations (Weiss *et al.*, 2002).
- *Selecting* : Not all concepts or procedures need to be presented or clarified with the use of animations. Selection has to be done on ground of the learning objectives, since preference is given to subjects that are crucial to achieve the learning objectives. Furthermore, when it is hard to describe the concept or procedure statically (with texts and static visuals) and cognitive load will be too high when a static description is used, animation is probably useful to clarify the concept or procedure.

Table 1.5: Classification of the subject matter and a description of each class.

class	description
Fact	a statement or piece of information that is accepted as to be true or a real occurrence (Example: an apple colours brown after crushing.)
Rule	involves a prescribed guide for conduct or action (Example: if one wants to prevent browning of apple puree, one should add some citric acid.)
Principle	a comprehensive law or assumption concerning a natural phenomenon (Example: when an apple is crushed, the enzymes release and with oxygen from the air it catalyses the browning of the apple.)
Procedure	an ordered sequence of steps (Example: the procedure for the use of laboratory equipment or for using a computer program.)
Concept	idea underlying a class of instances: it gives an explanation of how systems (consisting of objects and processes and their relationships) work. (Example: preventing enzymatic browning by damaging the enzyme. To understand how to do so, a broad understanding of the enzymatic reaction is necessary.)

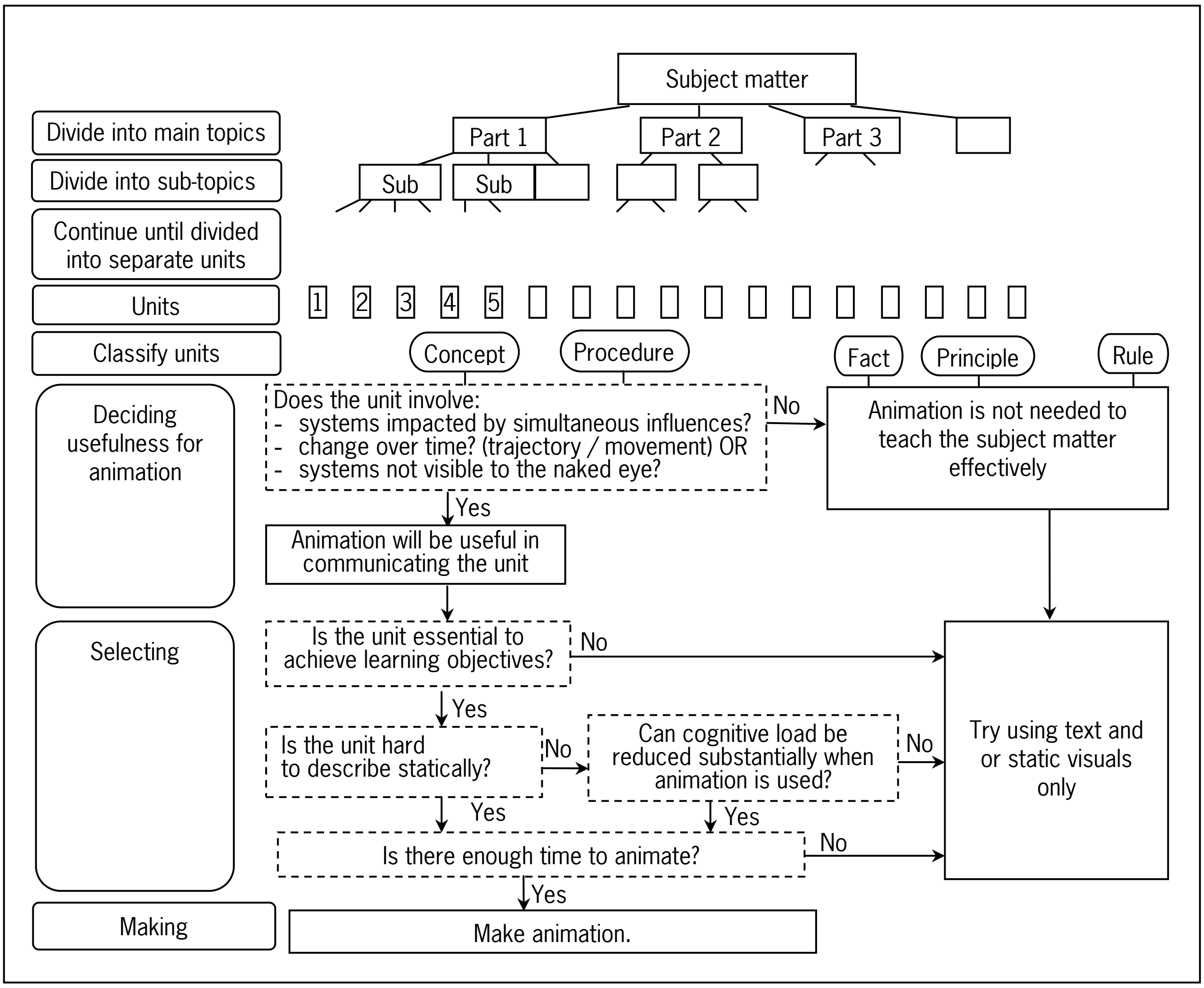

Figure 1.3: Decision model for the decision to use animation within digital learning material (adapted from Weiss and co-workers (Weiss *et al.*, 2002)). Boxes with dashed lines are decision questions.

Divided and classified subject matter of Hydrophobic Interaction Chromatography (HIC).

main topic	sub-topic	unit	class	no.
Principle	HIC is used for separation		fact	F1
	HIC is an HPLC technique		fact	F2
	Elution in order of increasing hydrophobicity		fact	F3
Technique	Mobile phase	A mobile phase is used to transport the sample through the system	fact	F4
		Two liquids are used	fact	F5
		Ammonium sulphate	fact	F6
		Water	fact	F7
	Mixing chamber	In the mixing chamber the salt concentration can be regulated	fact	F8
	Syringe	The syringe contains the liquid sample	fact	F9
		The syringe is used to inject the sample into the system	fact	F10
	Injector	The injector is the inlet to the system	fact	F11
		It regulates the inlet of sample	fact	F12
	Column	The column contains small particles with an active surface	fact	F13
		The working of the separation	concept	C1
		The reason why the separation works	principle	P1
	Detector	The detector registers the compounds and gives a signal	concept	C2
		There are a lot of different detectors	fact	F14
	Screen	Development of the graph after injecting the sample	concept	C3
Application	Use of HIC	Preparative: separation and purification	fact	F15
		Analytical: identification and quantification	fact	F16
	Components	Components differ in polarity	fact	F17
		Components are mainly proteins	fact	F18
Results	Calibration curve		concept	C4
	Peak surface area		concept	C5

Choice for animation

question	concepts				
	C1	C2	C3	C4	C5
Does the unit involve:					
- systems impacted by simultaneous influences?	Yes	No	No	No	No
- changes over time?	Yes	Yes	Yes	No	No
- Systems not visible to the naked eye?	Yes	Yes	No	No	No
Can animation be useful to explain the unit?	Yes	Yes	Yes	No	No
Is the unit essential to achieve learning goals?	Yes	Yes	Yes		
Is the unit hard to describe statically?	Yes	No	Yes		
Is there a possibility in reducing cognitive load?		No			
Is there enough time for the developer to animate?*					
Animation?	Yes	No	Yes		

*: The answer to this question depends on the situation of the designer/developer.

Figure 1.4: A worked out example of the decision model for the use of animations

Worked out example in using the decision model

A worked out example of the decision model for a digital learning object on Hydrophobic Interaction Chromatography (HIC) is given in Figure 1.4. The learning objectives of this object are ‘being able to explain on what basis and how Hydrophobic Interaction Chromatography separates the components in a sample' and 'being able to analyse the results from the separation of a sample with Hydrophobic Interaction Chromatography'.

The subject matter about HIC is first divided into parts, sub-parts and finally units, which are classified in facts, rules, principles and concepts (Figure 1.4, first table) regarding their content. After classification, it is investigated which units will be presented with animation within the digital learning object. All facts are excluded from animation. Concept C1, *the working of the separation*, involves "systems impacted with simultaneous influences", "changes over time" as well as "not visible to the naked eye". The concept is indeed essential to achieve the learning goals. It is also hard to describe verbally. So, animation of this concept will be useful (Figure 1.4, second table). The concepts C2, C4 and C5 do not need to be animated as is shown by the analysis in Figure 1.4.

DESIGN, DEVELOPMENT AND EVALUATION OF DIGITAL ACTIVATING LEARNING MATERIALS

Design and development process

The process of the design and development of digital learning materials can be viewed as a sequence of the following activities. The designer starts with articulating design requirements. Design requirements represent demands that the final digital learning material should meet. The designer also formulates a list of design guidelines that helps him/her during the design process. Various (instructional) principles are the basis for these requirements and guidelines as will be explained later. During the design process, ideas are formulated and worked out and these ideas are translated into a prototype of the digital learning material. The (formative) evaluation(s) of the prototype aim(s) for verifying whether the design requirements are satisfied and help to come up with adjustments of the prototype. According to the improved prototype, digital learning material can be developed that satisfies the requirements and that can be used on regular educational settings.

According to Weston and co-workers (Weston *et al.*, 1999) the principles to be considered when designing learning materials can be classified into four groups: instructional design (pedagogical issues), subject matter (content issues), language (semantic and syntactic issues) and presentation (physical issues). For the design of digital learning materials these authors introduced nine additional considerations: impact on learning, student computer literacy, student computer access, infrastructure, interactivity, navigation, evaluation, content accuracy and recency, and loading speed and bandwidth. Although this model is quite extensive and complete, it is also quite inhomogeneous in its classification; most of the nine additional considerations are related to the four principles.

A different classification, a classification into three fields of principles, is possible: 1) education, 2) subject matter and 3) information and communication technology (ICT). The classes Language and Instructional design fit in the field of education. The nine additional considerations can be divided into technical considerations (the field ICT) and considerations for Instructional design (the field education). The principles within the class Presentation are related to computer technical principles (the field ICT) or to educational principles (the field education).

In this thesis, design guidelines and design requirements for the design of digital learning materials are based on the three just mentioned fields, as represented in Figure 1.5.

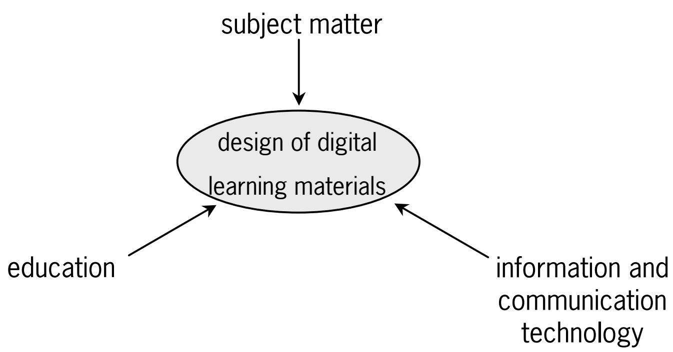

Figure 1.5: Relation of the fields of education, subject matter and ICT with the design of digital learning materials.

Subject matter

The professional field of the subject matter describes the learning goals of the learning materials and also depicts the course content of the learning materials. The subject matter food chemistry as well as the learning goals of the courses Food Chemistry and Advanced Food Chemistry have been described in the first part of this introduction.

Education

In order to design learning materials successfully, it is necessary to account for factors that facilitate learning. Incorporating these factors into the design of digital learning materials is essential to develop instructionally sound learning materials (Martinez, 2002). The educational principles on motivation, on cognitive load and on support, as described earlier in this introduction, are used as a basis for the design and development of the learning materials. Depending on the learning goals and subject matter of the learning material also other educational principles can be used as a basis for the design of the learning material. For example, the design of learning material with a learning goal related to the skill 'problem solving' should be based on educational principles about problem solving.

ICT

For the field of ICT, in relation to the design of learning materials, the restrictions and possibilities of ICT and principles in the field of human computer interaction (HCI) are of importance. In the case of designing digital learning materials one needs to take into account the possibilities of the learning management system used at the educational institute, as well as the possibilities of the computer programs used to develop the learning materials. Also, technical restrictions on the user side such as loading speed, bandwidth, and desktop configurations are of importance for the design of digital learning material. Related to the use of ICT is the field of HCI. The design of the interface of digital learning materials is a critical consideration to gain the maximum benefit for students (Evans *et al.*, 2004). There are several guidelines from HCI that provide a functional user interface design such as structuring the material to more than one level and providing sufficient navigational information and navigational tools.

Evaluation of the digital learning materials

The research described in this thesis is a design oriented research, which means that we are mostly interested in the design and development process of learning materials for food chemistry. Proving the effectiveness of digital learning materials is a time-consuming activity and is not in the scope of our research.

To evaluate if the process of design, development and implementation of the digital learning materials has brought us to our goal, we will evaluate whether the learning materials satisfy the design requirements. This can be done by evaluation with students, but also with teachers and with experts from different fields (e.g. education, user interface design, food chemistry).

Table 1.6 gives an overview of the types of evaluations that will be used in this thesis. In this research, most emphasis will be put on the evaluation by *case study*. The case studies are performed with the final digital learning materials. The main evaluation tool within the case studies is a questionnaire. The questions are (directly) related to the design requirements, so the answers of the students give an indication whether the learning material satisfies the design requirements.

Table 1.6: An overview of the types of evaluation that will be used in this thesis.

type of evaluation	description / goal
formative evaluation with students	A formative evaluation is an evaluation of the prototype, to verify whether students can work with the learning material efficiently and to detect possible technical or content errors. The learning material can be tested by one student, a few students, or in the normal educational setting in the course. Depending on the number of students, this evaluation is one-on-one with the designer or is similar to the case study as described below.
(formative) evaluation with experts	Experts are teachers, educational experts, subject matter experts and experts in user interface design. Most of these expert evaluations should be formative, to check for errors from in content, lay-out or from an educational point of view, before students are going to work with the learning materials. Evaluations (e.g. with teachers and an educational expert) can be a regular or a one-time event.
case study with students	The learning situation will be described thoroughly. Students work on the learning materials in the normal educational setting (i.e. during the course) and are not aware of being a subject of investigation. If possible, students are observed while working on the learning materials. Students fill in a questionnaire specifically designed to evaluate the learning materials and to test the design requirements related to student use. If applicable, also a standard course evaluation questionnaire is used.
interviews with students	Students are interviewed by asking them to comment on statements, to answer questions, or to give opinions. Interviews need to be planned carefully to make sure that useful results arise from the conversation. The way the interviewer asks the questions can highly determine the answers that are given. Therefore, the results from this evaluation type need careful handling.
examination questions	During the examination phase of the course, in which the digital learning material is used, students have to answer questions that are related to the knowledge and skills that they could have acquired by working on the digital learning material.

When evaluating learning materials it is important to consider the context in which the learning material is applied (Laurillard, 1994; Pawson and Tilley, 1997; Scanlon *et al.*, 1998; Yildiz and Atkins, 1993). The reason for this is that it is known that the outcome of an evaluation is influenced by the context in which the learning material is applied (Pawson and Tilley, 1997). The context depends on, for example, the student's prior knowledge, the computer room arrangements, sufficient time, number of persons in the group, and the assessment of the task (will students be graded, is use compulsory) (Laurillard, 1994). Because of the influence of the context, the case studies will take place in the normal educational setting. When evaluating in the normal educational setting, most students will not be aware on forehand that they are subject to investigation and will behave as normal as possible. Moreover, the context should be described to be able to explain the results of the evaluation within this context.

Formative evaluations (with students and experts) are performed with the prototype learning materials to detect errors and to find out whether students are able to work with the learning materials.

An *interview* with students can be performed when more information is necessary than could be collected with questionnaires.

When possible, the results of *examination questions* are used to give an indication of the effectiveness of the learning material. These results are only an indication. Since students also follow lectures, have laboratory classes, read and study their textbooks and readers, it is impossible attribute the results of the examination completely to the use of the digital learning materials.

AIM AND OUTLINE OF THE THESIS

It is expected that, because of the advantages of digital learning material in comparison to non-digital learning resources, with digital activating learning materials efficient and motivating learning activities can be enabled. These expectations are based on the idea that activation of students with digital learning materials is more efficient for both teachers and students than with non-digital learning materials, amongst others because of the just in time support that can be provided. Moreover, an educational institute can provide students with digital activating learning materials with little effort, from anywhere in the world. Likewise, also students can easily access the digital learning material with little effort.

It is the aim the research described in this thesis is to design digital activating learning materials for food chemistry education according to a rational design process to take advantage of the just mentioned advantages. The three learning materials that are designed within this research are:

- *The exercises* : to support students extensively in acquiring the required knowledge level.
- *The assignments on quantitative aspects* : to support students in acquiring quantitative problem solving skills in relation to the field of food chemistry

- *The assignments on research experiments* : to support students in learning how to design experiments: what options they have in analysing food and how to make choices between these options.

These learning materials are developed and subsequently implemented and evaluated in several courses and serve as a proof of feasibility of the design oriented research.

After this introductory chapter, four chapters deal with the design and evaluation of the just mentioned three sets of digital activating learning materials, for the courses Food Chemistry and Advanced Food Chemistry. *Chapter 2* describes the design of the digital exercises and gives an extended description of the exercises. *Chapter 3* describes the evaluation of the digital exercises. The results of the evaluation lead to a few hypotheses on how context can influence the use of activating digital learning materials. *Chapter 4* describes both the design and evaluation of the assignments on quantitative aspects and shows how activating digital learning materials can be used to make education more efficient. *Chapter 5* describes the design and evaluation of the assignments on research experiments. This chapter shows how digital learning materials can be developed that support students in learning to apply a scientific research method, which is hard to teach within laboratory classes. These four chapters are followed by a general discussion, *chapter 6*, discussing specific properties of the digital learning materials.

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Chapter 2 – Design of Digital Exercises

ABSTRACT

A complete set of digital exercises for the course Food Chemistry has been developed. The major function of the exercises is to promote active acquisition of food chemistry knowledge. This paper describes the design process and the result of the design process. Design guidelines and requirements were derived, based on theories about cognitive load, motivation and active learning. The digital exercises were designed according to these guidelines. Next, teachers, students, and experts in (food) chemistry, education and user-interface design tested the digital exercises against the design requirements in formative evaluations. The exercises are described in detail, with several illustrative examples. An in depth view on the possibilities to create digital learning objects for food chemistry in accordance to a set of practical guidelines is given.

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INTRODUCTION

The course food chemistry

At Wageningen University the course Food Chemistry is an introductory BSc level course of the Food Technology curriculum. In this course students should acquire basic knowledge on food chemistry and develop a set of laboratory skills. The main learning goals and content of this course are described in Chapter 1.

The course includes a multitude of different facts and concepts in great detail. Most students feel initially overwhelmed, intrinsic motivation of the students is low and the course lacks learning material that invites active learning. These are probably the reasons why the acquisition of the knowledge and concepts by students is low: the student's ambition is limited to "being able to pass the exam". Although students indicate during further education that the course is useful for the food science curriculum, over the years teachers in follow up courses report low retention of the knowledge that should have been acquired in the introductory course.

Digital exercises

Digital exercises are interactive questions that invite students to practice on all kinds of topics within food chemistry. The digital exercises are designed mainly to facilitate the acquisition and use of domain specific knowledge. There are several reasons why specifically digital exercises are developed. Exercises give the opportunity for the students to learn by being active, to test their knowledge, or to prepare for examination. Exercises can be used in several ways, e.g. as self-study, in the lectures, and during working classes. Exercises can support active learning of concepts over a wide range and the number of possible types of exercises allows for sufficient variation. Earlier, lectures were used to articulate the details of several food chemistry concepts to the students. Exercises can take over this part, so there is more time in lectures to dedicate to the social context of food chemistry. Also, the opportunities of digital learning material are several: colourful visuals can be produced at low costs, there are many possibilities to activate the student and to give immediate feedback to various students at the same time, the maintenance cycle can be short, and distribution is easy.

The design process

According to Weston and co-writers (Weston *et al.*, 1999) the design of digital learning material should follow general guidelines that come from education (instructional design), subject matter (content issues, learning goals), language (semantic and syntactic issues), presentation (user interface design) and computer technical issues. In this chapter those design guidelines that have played a major role in the design process for the food chemistry digital exercises will be highlighted. The design process is visualised in Figure 2.1. In the first stage of this process, design guidelines and requirements were drafted from the field of education, (food chemistry) subject matter and learning goals, and user interface design. Guidelines direct the process of design: they can be used as a compass heading that gives direction along the way to the final design. Requirements are demands that the final design should meet. The second stage resulted in trial digital exercises. The third stage of the design process existed of the exposure of the trial exercises to various formative evaluations. In these formative evaluations experts and students tested whether the exercises satisfy the requirements. These evaluations resulted in adjustments to the trial exercises and led to the final digital exercises.

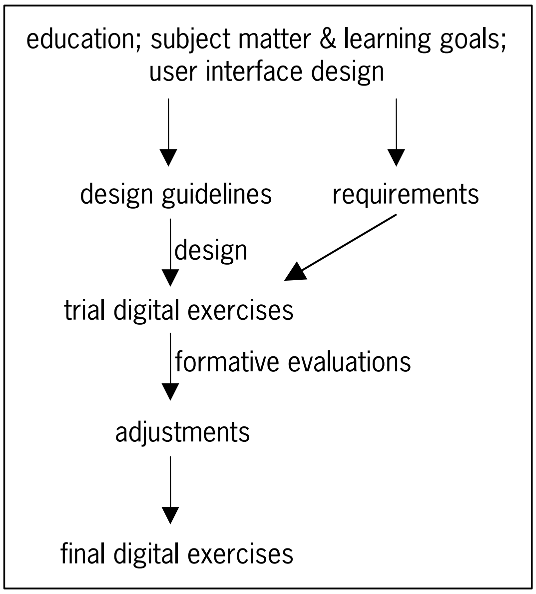

Figure 2.1: The design process of digital learning material.

In this chapter the design guidelines and requirements are listed, followed by a description and discussion of the formative evaluations and the proposed adjustments. Finally, a description of the final digital exercises is given in detail.

DESIGN GUIDELINES

Design guidelines based on the field of education

The knowledge, insights and skills that students acquire during the course Food Chemistry are considered necessary as a basis to successfully complete problem oriented education in the curriculum Food Science, to understand and solve problems during (future) work, and as a starting point for further education including life long learning. The laboratory of Food Chemistry at Wageningen University supports the opinion that a successful academic researcher should have an extensive body of domain specific knowledge (Owen and Sweller, 1989). Indeed, students often face difficulties with problem solving because of lack of knowledge next to information overload, experience, confidence and the mental flexibility to observe new ideas (Johnstone, 2001). The main purpose of the digital exercises is to facilitate the construction of the large body of detailed knowledge that is considered essential in food chemistry.

Given this main purpose and the characteristics of the subject matter, for the design of the digital exercises practical guidelines were derived from three perspectives on education: 1. cognitive load, 2. motivation of students, and 3. active learning.

Cognitive Load Theory

In cognitive psychology, working memory refers to a limited capacity system allowing the temporary storage and manipulation of information necessary for complex tasks such as comprehension, learning and reasoning (Baddeley, 1992; Baddeley, 2000). Cognitive load (CL) refers to the total amount of mental activity imposed on working memory at an instance in time. The Cognitive Load Theory (CLT) (Kirschner, 2002; Sweller *et al.*, 1998) assumes a limited capacity of working memory and a very large long term memory that holds schemata. CL (or working memory load) may be affected by the instrinsic nature of the material, by the manner in which the material is presented and the activities required from students (Bannert, 2002; Kirschner, 2002; Sweller *et al.*, 1998). CL induced by the manner in which the material is presented can be reduced by a good design of the learning material, in particular CL induced by the intrinsic nature of the learning material can be reduced by adequate sequencing the information (Bannert, 2002). CL induced by activities required of students that are relevant to construction of schemata should be increased and CL induced by activities that are irrelevant to construction of schemata should be minimised (Sweller, 1988; Sweller *et al.*, 1998).

Especially for a course as food chemistry, in which many dissimilar facts are related (the intrinsic nature of the material), it is very important to make sure that adequate levels of CL are imposed. To impose adequate levels of CL guidelines g1 to g6 in Table 2.1 were formulated for the design of the digital exercises. Important aspects of these guidelines are prior knowledge, adequate sequencing of information, just-in-time presentation of information and visualisation.

Motivation of students

Motivation is essential to learning: the extent of learning achieved can be modulated by the strength of the drive and its underlying motivation (Hull's drive reduction theory, Hull, 1940). Keller (Keller, 1983) established a model on motivation of students: the ARCS model. This model identifies four essential components for motivating instruction. The four components are Attention (arouse and sustain curiosity and interest), Relevance (make a connection to students' needs, interests, and motives), Confidence (help students develop a positive expectation for successful achievement) and Satisfaction (provide extrinsic and intrinsic reinforcement for effort).

For the design of motivational exercises the design guidelines g2 and g7 to g14 in Table 2.1 were derived from the ARCS model. Guidelines g8 and g12 are related to attention. Guidelines g9 and g10 are related to relevance. Guidelines g2, g7 and g11 are related to confidence. And finally, guidelines g11, g13 and g14 are related to satisfaction.

Active learning

Several authors assert that active learning is a necessity for understanding, acquiring knowledge and retention of this knowledge (Anderson, 1995; Keyser, 2000; Merriënboer, 1997). By active learning students are actively working with (prior) knowledge and information that is presented during the activities. In this way knowledge can be integrated into existing schemata or new schemata can be constructed on the particular topics of each exercise. These schemata are important for being able to work efficient on similar topics in research, future work and future learning (Owen and Sweller, 1989).

Exercises demand students to act and are, therefore, by definition activating. Whether this activation is effective in facilitating knowledge and schema acquisition by students depends on what students need to do in the exercises and the way the exercises are built. Design guidelines g15 to g18 in Table 2.1 were used to develop effective activating digital exercises.

Table 2.1: Guidelines for the design and development of digital exercises.

short description	extended description
g1: Use prior knowledge of the student as an entry point of an exercise. +	The prior knowledge of the student is related to knowledge from former (chemistry) courses. Also, take into account that the prior knowledge of the students can be incomplete or incorrect (Ausubel, 1968; Biemans, 1997).
g2: Include only one new concept per exercise. +	The exercise may contain different concepts, but only one should be new. (adequate sequencing of information: Bannert, 2002).
g3: Present relevant information just in time (JIT). +	All necessary information should be present or easily accessible (Kester *et al.*, 2001).
g4: Use visuals when explaining a concept and relate words and visuals directly. +	Accompany images with words (Mayer, 2003; Denis, 1994; Anderson, 1995). Corresponding words and pictures should be presented visually integrated rather than separately (Mayer, 2003; Mayer and Moreno, 2003, Sweller *et al.*, 1998).
g5: Incorporate activities related to acquisition of schemata.	See also guidelines g16, g17 and g18 on active learning.
g6: Design a user-friendly user interface.	See also guidelines g21, g22, g23 and g24 on user interface design.
g7: Gradually build up the difficulty of the exercises. +	A range of exercises should start with rather simple exercises, e.g. dealing with basic information, gradually moving to more difficult exercises. In this way students are guided in their search to understand the concepts.
g8: Provide novelty. +	Provide novelty by using each time a different type of exercise: different kind of technique, different kind of subject.
g9: Provide examples. +	Provide examples from daily life and show relations to the subject matter.
g10: Show importance of subject matter. +	Make clear what are important concepts within the subject matter and make explicit the reason of this importance.
g11: Provide challenging exercises.	Challenge students by asking them to do something rather complex, but still manageable.
g12: Include a motivational element. +	Include a motivational element in those exercises that support the learning of factual knowledge, which does not seem at first hand relevant to the student, to prevent that these exercises are too easy or boring.
g13: Give opportunities to test.	Give students the opportunity to test their knowledge or to learn what they still do not know.
g14: Provide a performance indication.	Provide an indication, for example a score, which tells the student how well he/she performed and which will presumably motivate the student to redo an exercise or to minimise the number of mistakes.
g15: Force students to take action. +	Force students to take action, so that necessary information will only be attained by this action. The information is than immediately catching the eye of the student.
g16: Promote active thinking.	Design exercises in such a way that active thinking is more beneficial than just clicking around (guessing).
g17: Provide hints and feedback. +	Provide hints and feedback to induce or to guide the thinking process of the student. In this way students are able to finish the exercise independent from others.
g18: Promote elaboration of knowledge.	Design exercises that promote meaningful elaboration of students' *know-what* knowledge and *know-how* knowledge.
g19: Follow learning goals.	Do not lose sight of the learning goals at any moment during the design.
g20: Strive for accuracy.	Make sure that the content of the exercises is accurate from the viewpoint of the subject matter of food chemistry.
g21: Strive for consistency. +	Be consistent in colour, navigation, buttons, screen layout, and typeface.
g22: Assist in navigation.+	The student should be able to know "where" he/she is in the program and how to get somewhere.
g23: Use colour in a functional way.	Colour is functional to emphasise information, to increase clarity or comprehensibility and to increase appeal.
g24: Keep the number of colours low.	Never use more colours than necessary and try to keep the number as low as possible.

+: These guidelines are elaborated in more detail in the part "description of the digital exercises".

When looking at the guidelines g1 to g18 it becomes clear that some guidelines can be based on both CLT as well as on theories about motivation and active learning. For example, if students are motivated to do something an active behaviour will be induced, or if cognitive overload occurs students will get frustrated and motivation will drop.

Design guidelines based on Food Chemistry subject matter and learning goals

There are two important guidelines that the learning material should follow from the point of view of food chemistry: g19, which deals with learning goals and g20, which deals with the accurate content of the exercises (see Table 2.1). It seems natural that these guidelines are important, but still it is essential for the success of learning material to constantly control during the design process whether for instance the subject matter is accurately presented. Our experience shows that while designing learning material all attention tends to be directed to good educational practices and nice examples and consequentially less attention is directed to accuracy. Subtle errors are introduced quite easily in this way.

Design guidelines based on user interface design

User interface design is the discipline that holds theories about designing computer interfaces. Guidelines that are described by Marcus (Marcus, 1997) about Graphical User Interfaces (GUI) are followed during the design of the digital learning material. Guidelines mentioned in Table 2.1 are g21 about consistency, g22 about navigation, and g23 and g24 about colour.

DESIGN REQUIREMENTS

Table 2.2 lists the set of design requirements for the digital exercises, the source of each requirement and how this requirement is evaluated. The design requirements and design guidelines are derived from the same sources. The requirements are used by the evaluators. The designer used the guidelines as well as the requirements to direct the design process.

Table 2.2: Requirements for the design, development and evaluation of digital exercises.

requirement	**source**	**evaluation**
r1: The exercises are clear. (It is clear what needs to be done and the content is clear.)	ED (clt, mot)	MSc-students + case study
r2: The exercises are manageable. (The student is able to solve the exercise.)	ED (mot)	MSc-students + case study
r3: Students see the digital exercises as a valuable addition to the readers.	ED	MSc-students + case study
r4: The exercises are used by students on their own initiative.	ED (mot, act)	case study
r5: The exercises are fun to work on.	ED (mot)	case study
r6: The content of an exercise is understood after completing the exercise.	ED (mot)	case study
r7: Students are able to recognise the exercises in sections of the readers.	ED (mot)	case study
r8: Sections of the readers are according to students easy to remember after completing the exercises.	ED (clt, mot)	case study
r9: Sections of the readers are according to students easy to understand after completing the exercises.	ED (clt, mot)	case study
r10: Students are motivated not to guess too much.	ED (mot)	case study
r11: Students are motivated to redo an exercise when the performance for that exercise was low.	ED (mot, act)	case study
r12: The exercises fulfil a need of those students who like to learn in an active and visual way.	ED (mot)	case study
r13: Students feel they learned much from doing the exercises.	ED (mot)	case study
r14: Students feel that the exercises contributed to the capability to successfully pass the final exam.	ED (mot)	case study
r15: Experts in pedagogical content knowledge observe the digital exercises as a valuable addition to the readers.	ED	experts chem + edu
r16: Experts in the field of education confirm that broadly accepted views in their field have been applied correctly in the digital exercises.	ED	experts chem + edu
r17: The teachers confirm that the content of the exercises is accurate and relevant.	SL	teachers
r18: Teachers confirm that the learning material supports the achievement of the learning goals.	SL	teachers
r19: Experts in (food) chemistry confirm that the exercises apply accepted scientific views on (food) chemistry in a justified manner.	SL	experts chem + edu
r20: At least one user-interface expert confirms that generally accepted views on user interface design are applied in a justified manner.	UID	expert UID
r21: At least one user-interface expert confirms that visualisation is realised in a justified manner.	UID	expert UID

ED: Education (**clt**: cognitive load theory, **mot**: motivation of students, **act**: activation of students), **SL**: (Food Chemistry) Subject matter and Learning goals, **UID**: User Interface Design, **chem**: chemistry, **edu**: education. **case study**: these requirements were and will be tested in a series of case studies with students in regular settings at different universities.

SHORT DESCRIPTION OF THE TRIAL DIGITAL EXERCISES

For each subject of the course Food Chemistry (proteins, saccharides, lipids, phenolic components, and enzymes) trial digital exercises are designed according to the above listed design guidelines. These trial exercises are grouped in sequences of at most 10 numbered exercises. There is a score incorporated within the exercises. For each exercise 10 credit points can be obtained. The sequence of exercises is concluded with a score overview, which shows the students the score of each exercise and the total score for the sequence. To re-do an exercise in the middle of a sequence of exercises, one has to start a sequence from the beginning. Exercises provide hints and feedback and differ greatly in difficulty and type.

The trial exercises were subjected to formative evaluations with respect to different sets of design requirements.

FORMATIVE EVALUATIONS OF THE TRIAL DIGITAL EXERCISES

The trial exercises have been subjected to formative evaluations, as was shown in the design process (Figure 2.1), in order to find out whether the exercises met the requirements. The following four formative evaluations have been carried out: (1) an evaluation by expert teachers on the subject, (2) an evaluation by MSc students, (3) an evaluation by a user interface designer, and (4) an evaluation by experts in (food) chemistry and education. The formative evaluations are discussed in this chapter in their chronological order. Every next evaluation was carried out with learning material that was improved according to the previous evaluation. The order of the evaluations 2, 3, and 4 was mainly determined by practical constraints.

Evaluation by subject expert teachers

For each subject (proteins, saccharides, lipids, phenolic components, enzymes) two requirements (r17 and r18) were tested with a teacher, who is expert on the content of that specific subject. By processing the comments of the five expert teachers into the learning material the content became accurate, relevant and it was related to the learning goals.

Evaluation by master students

Four MSc students, who had just finished or were about to finish their MSc degree in Food Science, evaluated the learning material for the requirements r1, r2 and r3. They had followed the introductory course on food chemistry several years ago, and they had not followed any chemistry courses after this introductory course. This means that their knowledge of (food) chemistry was insubstantial and probably only slightly higher than the prior knowledge of our target group of students (BSc). The advantages of an evaluation with these master students were several:

- Because of slightly higher prior knowledge, the cognitive load induced by the exercises was lower than for BSc students. Thus, the effort of solving the exercises did not prevent them to direct sufficient attention to evaluate the exercises.
- During their study these students had gained experience with several kinds of learning material and were, therefore, probably more critical than BSc students.
- They were not afraid to criticise, since they will never deal with any of our teachers anymore.

The general opinions of the students about the learning material were as follows: they liked to do the exercises, most exercises were manageable and they certainly perceived the surplus value. It was judged frustrating that there is no possibility to navigate between the exercises, to re-do an exercise or skip an exercise within one sequence.

Explanation of difficult words, changes in the lay-out, corrections of semantic errors in the script of the computer-program, more hints or more specific hints, were the few improvements that were made after the sessions with the students. The possibility to navigate through the exercises within one sequence was not incorporated yet. This was first verified with the expert on user interface design.

Evaluation by an expert user interface designer

The expert in user interface design (MSc in industrial design) had several years experience as a user interface designer in many different (research) projects and designed several websites and computer applications. He evaluated the trial exercises for the requirements r20 and r21.

This expert confirmed that screen space has been used optimally and that the use of colours, symbols and layout in the concept exercises were sufficiently consistent. On his advice navigation functionality was added to each sequence in the form of a link to each exercise from any place within a sequence. Furthermore, on his advice the design of some buttons was changed to clarify the purpose of these buttons.

Evaluation by experts in chemistry and education

During a four-hour session five experts on respectively education (one with and one without chemical background), content pedagogy, food chemistry, and chemistry from several universities (University of Twente, University of Utrecht, and Wageningen University) were invited to look at five different exercises. The requirements r15, r16 and r19 were tested in this session.

The experts took their job seriously and were therefore critical. The overall judgement of the learning material was positive. Visualisation and the possibility of working actively with the information were both regarded as surplus value for education. In general the content was correct. The experts in education looked at the exercises from a perspective different from that of the experts in chemistry. One expert in education declined to give an explicit judgement for the exercises apart from a well defined educational setting. Criticism focussed mainly on insufficient or unsatisfactory feedback. According to all experts, except for the expert in food chemistry, three of the five exercises provided insufficient feedback or feedback that was not specific enough.

The digital exercises were designed for regular students as a complement to existing learning material as readers, books and lecture notes. During the evaluation no books or lecture notes were available to the experts. However, during the evaluation session it became obvious that some experts really needed the lecture notes or an alternative source of background information for the exercises. This explains to a certain extent the opinion of some experts that adequate feedback is missing. Still, the experts' criticism on feedback could be an indication that some exercises needed adjustments for feedback.

Besides some minor corrections in content, no changes were made to the learning material. Instead of enhancing and extending the feedback, we are working on providing more information on-line by implementing parts of the readers and developing more presentational learning objects. This will result in a body of learning material that will be completely self sustained. A case study is necessary to see whether feedback should be adjusted. It is too early to say whether the two requirements r15 and r16 are met. This requires a more thorough evaluation with experts in education.

CONCLUSIONS FROM THE DESIGN PROCESS

During the design and development the design guidelines were a good help to design learning material that is motivating, activating and that reduces the cognitive load of the students. The formative evaluations were based on the requirements. Hence, from the formative evaluations we can not conclude whether the learning material really is activating and motivating. Several experts and students took a critical look at the learning material and corrections were implemented after each evaluation step. Therefore we are confident that most requirements that were tested seem to be met. The exercises are now ready for case studies.

DESCRIPTION OF THE DIGITAL EXERCISES

This section describes the main features of the digital exercises. The section is structured on the basis of a selection of the design guidelines.

g1: Prior knowledge should be the entry point

The way prior knowledge is used as an entry point is threefold:

- level 1 exercises: exercises that are designed to brush up prior knowledge
- level 2 exercises: exercises that are designed to relate new knowledge to prior knowledge
- level 3 exercises: exercises that ask students to reason, to combine prior knowledge and new knowledge, and to draw conclusions

Level 1 exercises brush up prior knowledge, which is important knowledge for understanding various concepts in food chemistry. An example is an exercise about the structural forces in proteins. It is assumed that students are already familiar with these structural forces, so this exercise is designed to make students aware that this knowledge is also important for food chemistry.

The level 2 exercises add new knowledge to assumed prior knowledge: assumed prior knowledge is rehearsed and new knowledge is introduced and relations to food chemistry situations are shown. The aim of this kind of exercises is supporting the acquisition and elaboration of know-what knowledge. An example is an exercise in which the structural properties of monosaccharides that are of importance for food chemistry (glucose, fructose, galactose: structures that are assumed to be prior knowledge) are elaborated and are related with properties like taste and source.

Level 3 exercises also combine assumed prior knowledge and new knowledge. These exercises differ from type 2 exercises in the sense of reasoning: the aim of these exercises is supporting the acquisition and elaboration of know-how knowledge.

g8: Use each time a different type of exercise.

Several types of exercises were used, which means that there are several possible assignments a student can be asked to do. The different types that are used to make an interactive exercise are: multiple choice, multiple answer, categorising, matching, ranking, point out and fill in the blank. Cucchiarelli and others (Cucchiarelli *et al.*, 2000) gave a somewhat comparable list of question types.

In Table 2.3 each type of exercise and the reason why the designer could choose this type are given. The table also shows that the degree of freedom (number of choices the student has in performing the exercise) depends on the type and the way this type is used.
Each type of exercise was used for level 1, level 2 and level 3 exercises. By choosing a certain type the level of difficulty of the exercise was manipulated, for example by increasing the number of degrees of freedom. Table 2.4 gives an example for each type of exercise.

The digital exercises use basically four different possible actions to interact: fill in a number or letter(s), drag an object, click on an object, and mouse-over functions. These four actions give the designer plenty possibilities to make activating learning material. For each type of exercise all four actions were used.

Table 2.3: Different types of digital exercises that were used.

type of exercise	purpose of exercise	degrees of freedom depends on:
Multiple choice: Choose one correct answer from several options	Focus on definitional knowledge.	- the number of options
Multiple answer: Choose more than one correct answer from several options	Focus on the relationship of items to one specified category.	- the number of options - the number of correct answers - whether the student knows how many correct answers there are
Categorising: Group items into several categories	Focus on categories that exist in food chemistry, e.g. the 20 amino acids that can be grouped in several categories.	- number of categories - whether categories can hold a (for the student known) maximal number of items
Matching: Match items that belong together	Focus on the relation between items, e.g. relation between a structural and a physical property.	- presence of categories - number of categories - number of items (per category) - number of fake items
Ranking: Rank items into a correct order	Focus on processes or specific sequences in reactions.	- the number of items - the number of fake items
Point out: Point to a certain area in a visual (no specific areas are highlighted for pointing, since then this would be a multiple choice question)	Focus on the spatial position of a certain item (hot spot), e.g. the free amino group in a protein.	each position in a visual can be pointed out by a student
Fill in the blank: Fill in an answer, which can be a calculated number (no specific possible answers that can be filled in are given)	Focus on calculation.	any number can be filled in

Table 2.4: Example for each type of exercise.

technique	example
Multiple choice	*The exercise* : Where are the side-groups of the amino acids in an α-helix situated? *The options* : a. Inside of the helix b. Outside c. Both in- and outside (just one answer is right)
Multiple answer	*The exercise* : Point out which of these items are related to starch. *The options* : α-glucose, β-glucose, reducing sugar, non-reducing sugar, milk, potatoes, rice, bananas, meat, etc. (more than one answer need to be pointed) (see also Figure 2.6A)
Categorising	*The exercise* : Categorise each of the 20 amino acids according to their side-group. *The options* : For each amino acid there are 6 options. Students see that the categories have fixed numbers of items that it can hold.
Matching	*The exercise* : Select for each graph a reaction formula and the result from this reaction. *The options* : there are three graphs, three formulas and three results that need to be matched (see also figures 2.2C, 2.3A, 2.4A, and 2.5A)
Ranking	*The exercise* : Put the various stages of the formation of a gel in the right order. *The options* : there are 5 stages the first is "moving macro-molecules" and the last is "network can hold water"
Point out	*The exercise* : Point to the structural group in the protein molecule that reacts with sugar in the Maillard reaction. *The options* : A molecular structure is shown and the student can click anywhere in this structure. Only one spot corresponds with the right answer.
Fill in the blank	*The exercise* : Calculate the sugar concentration of a solution and fill this number in. The needed numbers and formula are given. *The options* : A blank is given where the student can fill in any number.

g2: One new concept at the time

The exercises differ in many ways. Each exercise is related to a specific learning goal, dealing with a certain topic. Each exercise is independent from another concerning the topic of the exercise, but the prior knowledge is increasing in the course of the sequence. There are several topics for the exercises as shown in Table 2.5 and many exercises contain combinations of topics. Each topic can be used for level 1, level 2 or level 3 exercises. Each topic may consist of many concepts, but during the exercise maximal one concept of the topic (-s) is assumed to be new to the student.

Table 2.5: Categorising the topics of the digital exercises.

main topics of the digital exercises
Molecular structures of components
Classification and names of components
Reactions of components
Properties of components
Definitions
Source / origin of the components
Processes
Methods of analyses and separation
Applications / examples from daily life / industry

g3: JIT presentation

JIT presentation of information can refer to the presentation of information at the beginning of an exercise, during an exercise or after completion of an exercise. Table 2.6 shows which type of information should be given at which stage and the reason for it.

Information before, during or after an exercise can be given in different forms, for example a table, a scheme, a static visual, a text or an animation. Information that is given during an exercise is accessible in two ways: 1. the information must be called up consciously (for example by clicking on a button), and 2. the information is feedback (hint or reaction on answer), which is given after submitting an answer.

Table 2.6: When information can be given and possible reasons for this moment.

when	reason(-s)
Beginning of the exercise	1. Activation of prior knowledge. 2. This information is necessary to start the exercise. By providing this information in the beginning students do not have to seek for it, which saves time and reduces cognitive load. 3. The exercise elaborates on the information that students read or saw just a moment ago, which is a form of rehearsal and application of knowledge.
During the exercise	4. During the exercise students need certain facts that they are not supposed to know by heart, but that are necessary to complete this exercise (e.g. the definitions of penta, nona and deca). 5. Students need information to be able to complete the exercise (e.g. they have no clue what to do or the number of possibilities is too large).
After the exercise	6. During the exercise students use their prior knowledge, common sense and presented information. After completion, students could need extra explanation, additional information or a summary, to reflect on the just acquired knowledge.

g7: Gradually build up the difficulty

The Food Chemistry course gives the students an introduction to the structures, important properties and important chemical reactions of the most important components in food systems: proteins, carbohydrates, lipids, phenolic components and enzymes. For each of the five components exercises are designed which are grouped in sequences of each maximal 10 exercises. In total 14 sequences are developed containing in total 107 exercises.

According to Sweller (Sweller, 1994) "difficulty of learning is closely related to the number of items that need to be learned and the level of association between these items, which is related to cognitive load". The difficulty of a task is also closely related to whether schemata already exist in memory to solve the task. If schemata do not exist, a task can be very difficult although cognitive load can be low. Hence, the topic, the number of concepts, the type of exercise (especially the number of degrees of freedom) and the prior knowledge of the student determines the degree of difficulty of the learning task. These parameters have been used to control the degree of difficulty of the exercises.

Both from sequence to sequence as well as within each sequence the difficulty of the exercises is gradually increasing: the first sequence is in general easier than the second and the third and the first question of a sequence is in general easier than the last question. For example the amino acid sequence contains exercises about what amino acids are and in what kind of reactions they are involved. The sequence on properties of peptides assumes that the students know about amino-acids, which means a higher assumed prior knowledge than the sequence on amino acids, and starts with exercises about peptide bonds and ends with exercises about specific known peptides and some functions. The last sequence of this subject, properties of proteins, assume knowledge about both amino acids and peptide bonds, which means that the assumed prior knowledge is even higher than the sequence on peptides. Students are therefore invited to start with the first sequence of a subject, but it is not a necessity. The sequences have the purpose to give guidance: by gradually building up the degree of difficulty of the concepts in the exercises students are guided in their search to understand food chemistry concepts. Each task within an exercise can be kept simple, while after a sequence of exercises many complex concepts are dealt with.

g4: Visualise and integrate words and visuals

Much can be presented visually. Examples are molecular structures, schemas, processes, drawings, tables, photos and animations. The use of colours, buttons, mouse-over functions and screen lay-out are important tools for visual presentation of information. Several examples of visualisation will follow (Figures 2.2, 2.3, 2.4, 2.5, 2.6 and 2.7).

g22: Strive for consistency, g23: Assist in navigation

Each sequence and each exercise has the same lay-out. Navigational information is consistently presented in the same area of the screen and colours and buttons are consistently used to assist the student in navigation. For instance the overall colour of the first sequence is different from the second and third sequence, so the student can distinguish the sequences.

Figure 2.2A shows the start of a sequence. The name of the sequence "applications of enzymes" shows the student the subject of exercises of this sequence. When clicking the start-button in Figure 2.2A the student starts this sequence of exercises and arrives at the first exercise, shown in Figure 2.2B. The navigation-buttons top left show the student that there are in total five exercises. The number of the exercise the student is working on is bold and the student can click on each of the numbers to go to any other exercise or can click on "score" to go to the total score list (Figure 2.2F). In this way the student is free to navigate to each exercise. Top right the student can see his or her score for that particular exercise. For each exercise the student can earn 10 points. Centred at the top the student can read what has to be done in this exercise. In this particular example the student first has to move his mouse over an amylopectin molecule, to find out which enzymes degrade which parts of the amylopectin molecule (Figure 2.2B).

By clicking on the assignment-button the student arrives at the real exercise (Figure 2.2C). The assignment-button is always used when the exercise starts with some information before going to the real exercise. In the exercise in Figure 2.2C the student has to indicate which graph corresponds with which enzyme preparation. In this example the student already filled in the answers and is about to click OK. In all exercises, for the students the function of the OK-button is checking the answer. After clicking OK, the computer indicates whether the particular answers are right or wrong (Figure 2.2D). By clicking on the arrow the student arrives at the end of the exercise, where some explanation is given (Figure 2.2E). An arrow-button is always used to go to a next stage within the same exercise. This is very often an explanation. Bottom right there is a link to the next exercise by means of a next-button. Clicking on the next-button is always bringing the student to the next exercises. At the end, the score of each exercise is shown in a score overview, as shown in Figure 2.2F.

g9: Provide examples from the food industry, from the lab and from daily life

By providing examples from food industry or daily life students see the use of the knowledge they have to learn. Examples can come from a butcher as in the example in Figure 2.3A, but it can also come from for example a lemonade factory (brown colouring in orange juice), a bakery (S-S-bridge forming in bread), or the taste of French cheese (lipid oxidation products).

The exercise in Figure 2.3A is built around the situation of a butcher who wants to develop three meat sauces. The sauces differ in pH and salt-concentration. Students have to tell what the meat structure will look like with each of the sauces (pH and salt-concentration both influence the water binding capacity of fibrillary proteins). In this exercise students combine three sauces and three representations of meat structure, by matching the number of the sauce to each representation. After correctly answering the question, the student arrives in Figure 2.3B. Some information is given during or before the exercise (e.g. the iso-electric point of actomyosine, see Figure 2.3A) and at the end the effect of pH and salt is explained (see Figure 2.3B). In this example a clear relation between food chemistry (water binding of proteins affected by pH and salt) and the food industry (meat industry) is shown.

g10: Make clear what are important reactions and concepts

In food chemistry there are a number of important reactions, for example reactions induced by polyphenol oxidase (a.o. enzymatic browning), lipid oxidation and Maillard reactions. These reactions are the main reactions that influence quality properties of food like taste, colour and shelf-life. The rate or existence of these reactions depends on many kinds of environmental properties like pH and temperature. To show how important these reactions are several exercises were designed that handle these reactions.

In Figure 2.4A an exercise is shown that is designed to show the effect of the enzyme polyphenoloxidase and the three most important reactions that are induced after oxidation by polyphenoloxidase and their effect. When clicking on hint, the student can get information about each of the reactions related to tea (see Figure 2.4B). Students are supposed to complete the scheme with the three reactions by dragging the molecules from the right to the appropriate spot on the left side. At this very moment in Figure 2.4A the user is dragging a quinone to, if the user knows the right answer, the top centre spot, from where three arrows go to three different reactions.

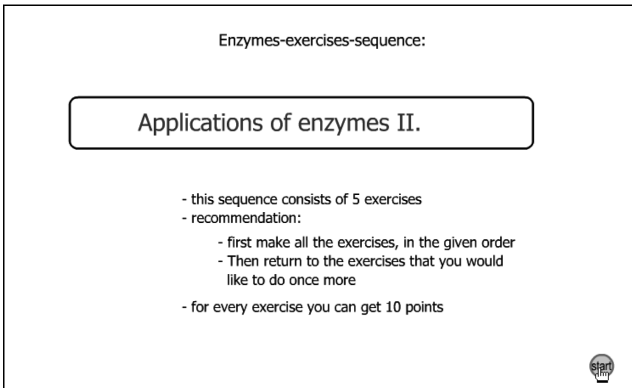

Figure 2.2A: start of a sequence

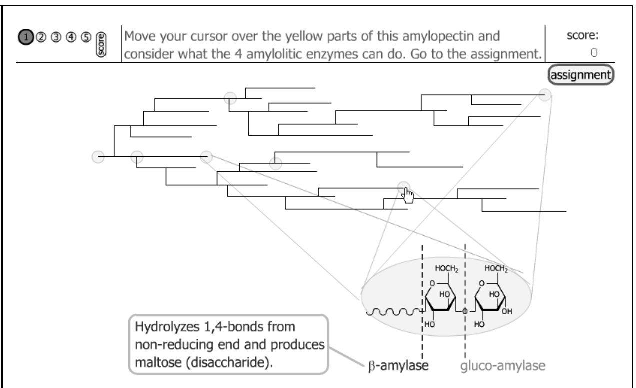

Figure 2.2B: information before an exercise

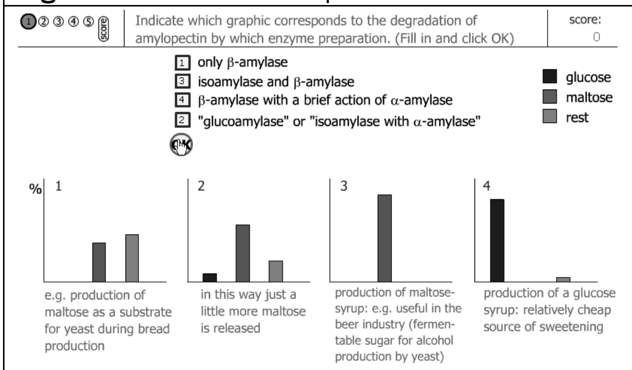

Figure 2.2C: the first exercise

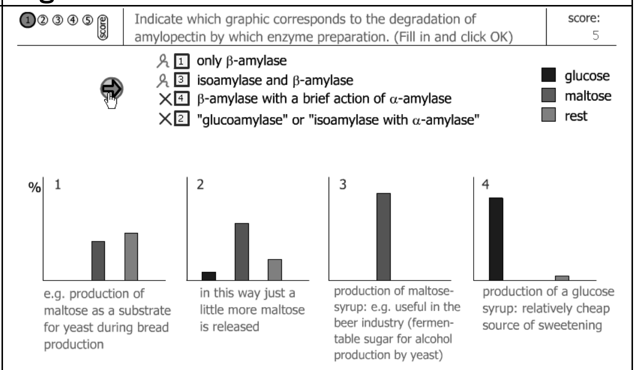

Figure 2.2D: right and wrong answers

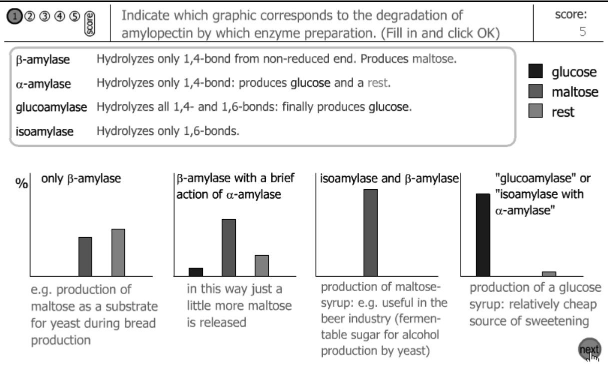

Figure 2.2E: end of first exercise, with link to second

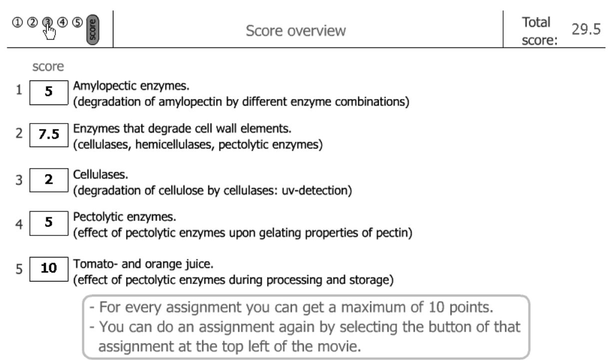

Figure 2.2F: end of a sequence: score list and total score

Figure 2.2: An example of various stages within a sequence of exercises.

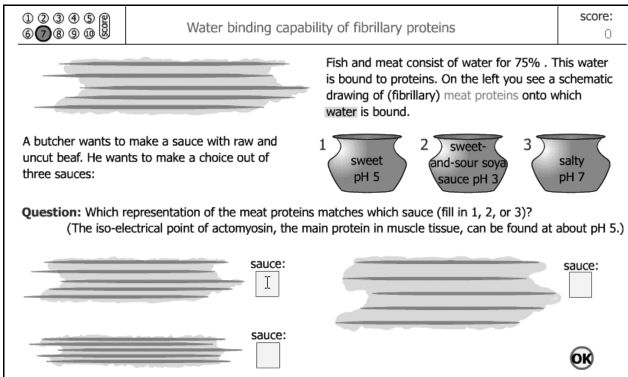

Figure 2.3A: Exercise with example from industry.

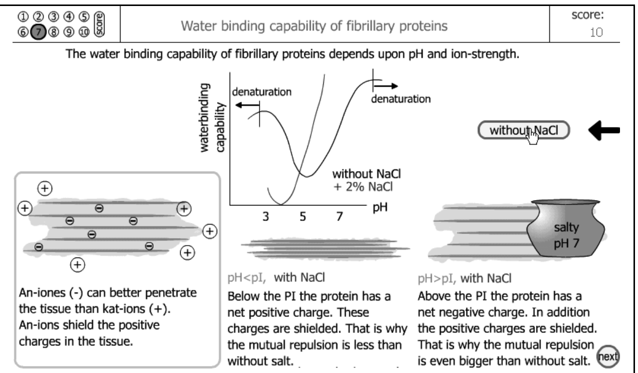

Figure 2.3B: Explanation after exercise.

Figure 2.3: An example of an exercise that provides an example from the food industry.

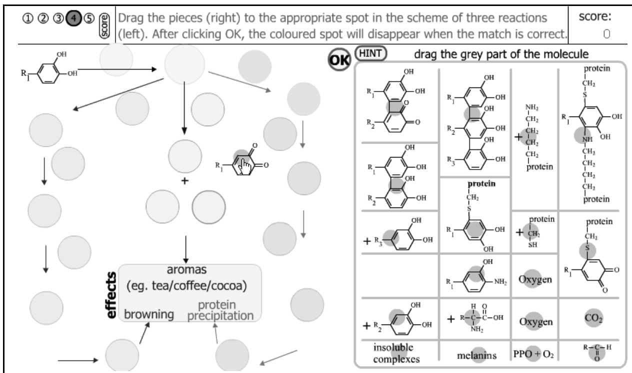

Figure 2.4A: Exercise that involves working with different reactions.

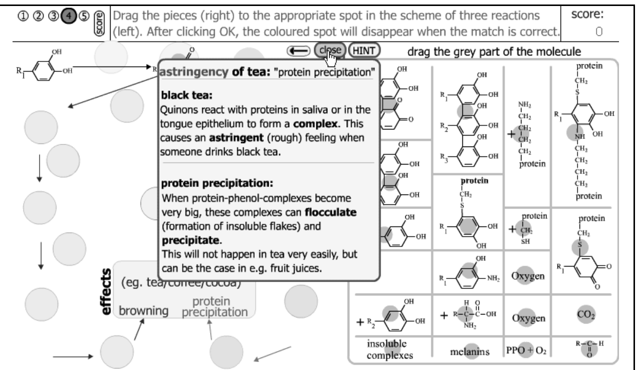

Figure 2.4B: Importance of the reaction become especially clear in the hints.

Figure 2.4: An example of an exercise that shows the importance of reactions induced by the enzyme polyphenoloxidase.

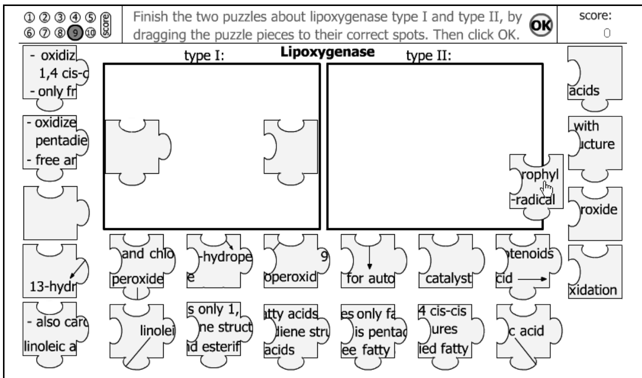

Figure 2.5A: Exercise that is a kind of game: a jig-saw puzzle.

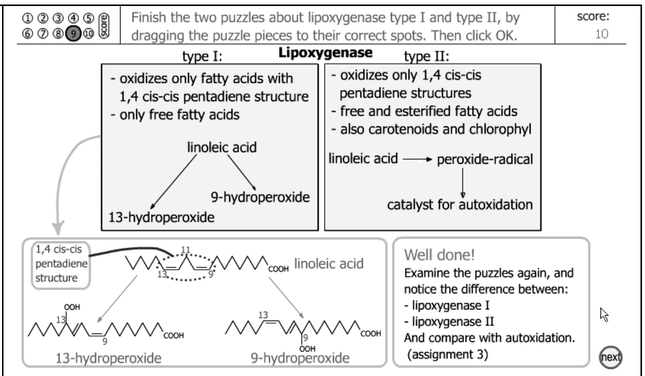

Figure 2.5B: Explanation after exercise.

Figure 2.5: An example of an exercise that includes a motivational element by means of a jig-saw puzzle.

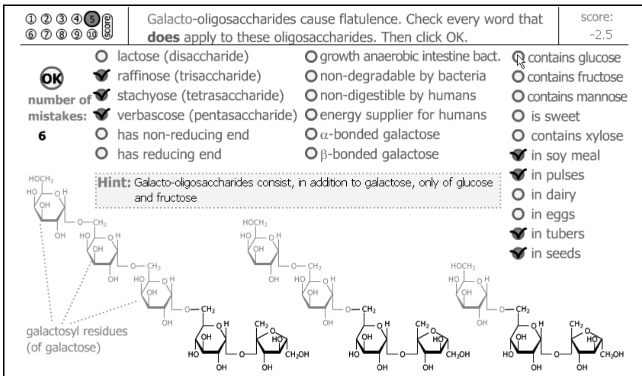

Figure 2.6A: Exercise with hints and feedback.

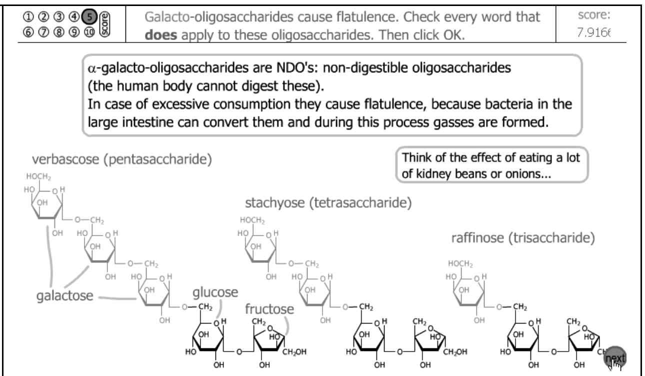

Figure 2.6B: Explanation after exercise.

Figure 2.6: An example of an exercise that provides feedback and hints.

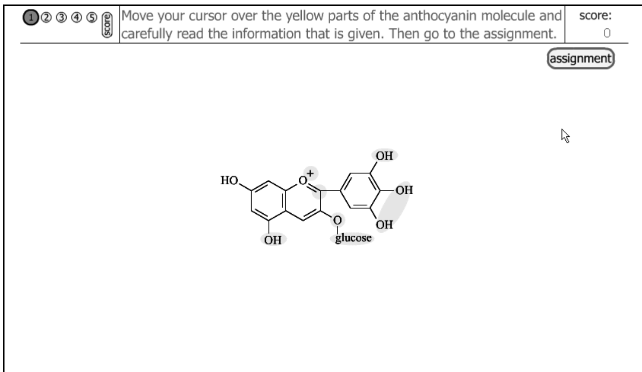

Figure 2.7A: An exercise where information is hidden behind certain areas of the molecule.

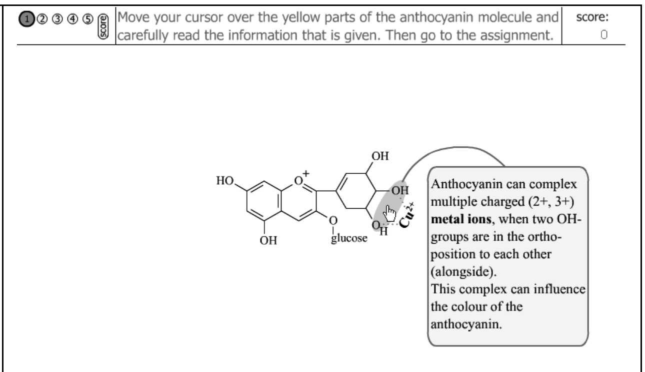

Figure 2.7B: By moving the mouse over the molecule information appears.

Figure 2.7: An example of an exercise that forces students to actions.

g12: include a motivational element

By using a game or anything else that increases extrinsic motivation when instrinsic motivation is likely to be low, a motivational element can be included in exercises, for example a mahjong game (Diederen *et al.*, 2002) or a jig-saw puzzle.

In the exercise in Figure 2.5A the student has to complete two jig-saw puzzles by dragging the puzzle pieces into the two squares. There are two possibilities to complete the two puzzles. The puzzle pieces fit in both puzzles so you could put all the pieces of the left puzzle on the right and the pieces of the right in the left and still have two complete puzzles. But, only one possibility is right: the pieces that belong to lipoxygenase type I should be dragged to the left puzzle and the pieces of lipoxygenase type II to the right. These two types both oxidise a specific structure in a lipid, but one type can react with only one kind of substrate and the other type with several. The screenshot Figure 2.5B shows the information that is given after completion of the two puzzles: there is some additional information and explanation what happens with linoleic acid when it is oxidised by lipoxygenase.

g17: provide hints and feedback

The digital exercises contain feedback and hints. The easiest form of feedback is an indication whether an answer is right or wrong. Apart from this, feedback could also give a reason why something is wrong. Hints are most of the time incorporated to guide the thinking process. Without these hints it could be very difficult for the student to decide what to do after a wrong answer. To help a little, the exercise gives the student a hint that is supposed to guide the student along a suitable line of reasoning or to give the student an indication that certain prior knowledge may not be correct.

An example of both feedback and hints is visualised in the screenshot from an exercise on galacto-oligosaccharides (Figure 2.6A). The student has to select those words that do apply to this group of saccharides. When clicking OK the student gets two pieces of information: 1. the number of mistakes (in this example 6) (which is a form of feedback) and 2. a hint. The hint is generated according to the answer of the student. So each time the student clicks OK a hint appears that is related to a word that still is not selected or should be deselected. When the number of mistakes is reduced to zero, the student reaches the end of the exercise, where some additional information is given (Figure 2.6B) (an example of "information at the end of an exercise").

g15: force students to actions

To catch or direct the attention of the student the exercises should contain elements that force students to an action. Without this action nothing happens. This was done in many different ways in the digital exercises, for example:

- Mouse-over function in where a student only gets the information after moving the mouse over a specific area
- Buttons that students have to click on to get information or to start a movie (animation)

An example of an exercise where students are forced to an action is shown in Figure 2.7A. In this exercise students first have to take a look at a molecule. At first instance, there is not much information on the screen. Students will only get information by moving the mouse over the yellow parts of the molecule, which is the case in Figure 2.7B. Students are forced to an action: without moving the mouse students will not have the necessary information. After reading all information students can go to the assignment (by clicking on button saying "assignment" on top in Figure 2.7A). In this assignment students need the information that they can read behind each yellow part of the structure. This exercise is a clear example of "information before an exercise".

CONCLUSIONS

In total 108 digital exercises have been designed, developed, evaluated and improved. The design process was guided by a set of design guidelines and design requirements. Sometimes guidelines and requirements overlap, but always guidelines and requirements are each others complement. During the design process the guidelines turned out to be very useful as a means to assure that the exercises are in line with the requirements. The implementation of the design guidelines resulted in a lot of practical experience on how to design activating exercises. This experience has been described in detail in the last section of this paper.

The formative evaluations were very useful to make sure that the exercises are usable and do not contain serious shortcomings in the form of bad user interface design, errors in content or didactical mistakes. Because of the formative evaluations, errors could be eliminated to make the exercises ready for real-life implementation in the course.

In short, this paper shows how guidelines are used to build a bridge between the theories on education and the practical challenge of designing digital learning material.

FINAL REMARKS

All exercises are developed with Flash5® (Macromedia) and are provided through the world wide web with the help of Blackboard®, a web based learning management system.
The exercises are used and evaluated in case-studies within the regular stetting at Wageningen University and Cornell University (USA). Students worked individually behind a computer during a few computer classes. Besides these classes, students could access the material anytime. Results from these case studies are showing a successful implementation of the product. A thorough description of these case studies is given in the Chapter 3.

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Chapter 3 – Evaluation of Digital Exercises

ABSTRACT

Digital exercises were designed and developed for food chemistry education. During the design process, design requirements were described for such exercises. The exercises were evaluated in three case studies, firstly to determine whether the exercises satisfy the design requirements with respect to students' use and secondly to provide insight into the effect of the course structure and organisation on the value that the students attribute to the exercises. The results show that the exercises meet most of the design requirements. Students found the exercises clear and helpful, and most students confirmed that these exercises helped them in their preparations for their examinations. Despite this, participation in the programme was low when working on the exercises was not compulsory. The differences in evaluation results between the three case studies can be explained by differences in the course structure and organisation.

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INTRODUCTION

The course Food Chemistry is a second year course for students in their Bachelors curriculum Food Science & Technology at Wageningen University. In this course, students acquire basic knowledge of food chemistry, i.e. qualitative and quantitative knowledge about important (bio-) chemical reactions in food and the influence of the processing conditions on these reactions, and finally, development of laboratory skills. To facilitate this, digital exercises have been designed and developed to motivate and activate the students.

For the design of digital exercises, a design (and development) process for activating and motivating digital learning material has been developed. In Chapter 2 the design process and, in particular, design guidelines and design requirements that are based on the field of education, on food chemistry subject matter and learning goals, and on user interface design are described in detail. These design guidelines and design requirements were followed during the design and development of a set of 106 digital exercises.

Education supported by digital learning materials is relatively new, compared to education through lectures, self-study with books, group work and laboratory classes. To usefully incorporate the digital exercises into the food chemistry course, which consists of several educational activities, one needs to answer questions such as, 'what should be the sequential order of different educational activities such as lectures and computer classes?', 'what is the effect of the number of lectures on the need for and use of digital learning objects?' and 'what may happen when there is no extrinsic motivation for the use of the digital learning objects (e.g. when their use is not compulsory)?'

The present chapter deals with the evaluation of the digital exercises in three case studies, each within a different course structure and organisation. The first two were carried out in the regular educational setting of the course Food Chemistry at Wageningen University in two successive years. In this setting the use of the digital exercises was compulsory in both case studies, but the number and type of lectures accompanying the digital exercises differed. The third was performed during the course Food Chemistry at Cornell University (Ithaca, NY, USA), in which the use of the digital exercises was optional.

The aim of these studies was twofold:

1. To determine whether the learning material satisfied the design requirements on student use, dealing with the influence of the context, the quality and user-friendliness of the design, the extent

to which the digital exercises assist in studying the reader, and the additional value of the digital exercises.

2. To collect information about the possible relation between differences in the students' appreciation of the digital learning material and differences in course structure and organisation.

THE DIGITAL EXERCISES

In total, 106 digital exercises were designed for food chemistry education. These exercises comprise interactive questions and assignments that invite students to practise on different topics within food chemistry. Chapter 3 provides a more detailed description of the digital exercises, as well as the rationales for the design decisions. In this section a brief description is given. The content of the exercises was based on the content of the reader used during the course at Wageningen University, since the digital exercises are in the first instance designed for this course. Since a course in food chemistry at another university most likely differs to some extent from that of the course Food Chemistry at Wageningen University, it cannot be guaranteed that all our digital exercises are equally useful to all food chemistry courses.

The digital exercises have the following seven main features:

- Exercises are grouped into sequences of at most ten exercises.
- A score for each exercise and a score overview for each sequence of exercises are incorporated into the exercises in order to motivate the students not to guess too much and to repeat an exercise with a low score (maximum score is 10; minimum can even be a negative score).
- Exercises contain diagrams, schemes, pictures and animations.
- Exercises contain examples from industry or daily life to show the usefulness of knowing and understanding typical reactions in food, e.g. lipid oxidation, Maillard reactions and enzymatic browning.
- Within each sequence of exercises the degree of difficulty is gradually increased.
- Exercises contain feedback varying from simple remarks (e.g. 'wrong' or 'right') to more detailed hints (e.g. specific feedback according to the student's answer) as well as different kinds of additional information.

- Exercises differ in the type of questions or assignments (e.g. multiple choice, categorising, ranking) and cover different topics (e.g. about molecular structure, reactions, definitions, applications).

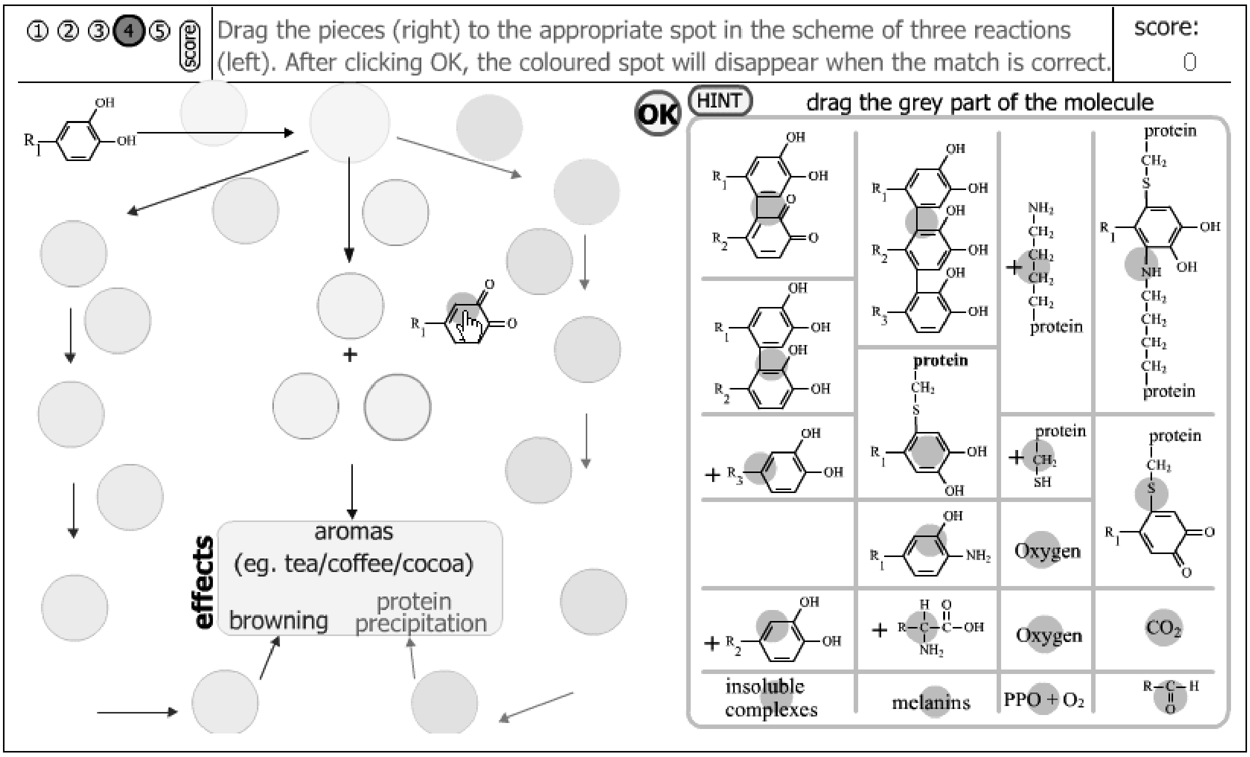

Figure 3.1: An example of an exercise: three reactions involving quinones

Exercises were developed with the software program Flash (Macromedia®) and were made accessible to the student by the web-based learning environment BlackBoard ®.

An example of an exercise is shown in Figure 3.1. Top left the student can see that he/she is working on exercise number 4 in a sequence of five exercises. The student can click on each of the numbers to go to a specific exercise or on 'score' to go to the score overview. The score overview shows the student the score for each exercise within this sequence. Top right the score for the current exercise is shown. Centred at the top it is written what should be done in this exercise. In this example, students have to complete a scheme of three different reaction pathways of quinones by dragging the molecules on the right to the corresponding spot of one of the pathways on the left. At the moment of the screenshot of Figure 3.1 the user was dragging a quinone out of the box on the right to move it to a spot on the left. Students can ask for information, by clicking on the 'HINT' button. In this particular case, on using this button the effects of oxidation of phenolic components are explained through the process of tea fermentation. By reading this explanation it becomes clear which reaction pathway causes browning, formation of aromas or protein precipitation.

EVALUATION METHOD

The digital exercises were designed according to design guidelines and design requirements based on theories of education, on subject matter and learning goals, and on theories of user interface design. Theories of education that were used are mainly the cognitive load theory (Sweller *et al.*, 1998; Kirschner, 2002), motivation of students based on the ARCS-model (Attention, Relevance, Confidence, Satisfaction; Keller, 1983) and active learning (e.g. Keyser, 2000). The sources for the different design requirements have been described extensively in Chapter 2. The requirements define operationally the goals of the design, and the variables, to which the requirements refer, can be measured. To be able to decide whether the learning material meets the requirements, minimum criteria need to be specified for each requirement. Some requirements need to be tested by students, some by teachers and some by specific experts as user interface designers, educational specialists or food chemistry specialists. This paper deals with the requirements that need to be tested by students, which is done with case studies.

The method of evaluation of requirements on students' use can be described as follows. The students work on the exercises and complete an evaluation questionnaire. When the results of the evaluation are equal to or higher than the criteria specified for each requirement, that requirement is judged to be satisfied. The details about how this is carried out are given later.

To investigate the influence of the course structure and organisation on the usefulness of the digital exercises for the students, the digital exercises were evaluated in different case studies.

The requirements

The requirements for the digital exercises that were evaluated in the case studies are divided into four related sets. These are listed in Table 3.1, together with the corresponding evaluation questions and criteria. The source for each requirement can be found in Chapter 2. The four sets of requirements will now be explained in detail.

The influence of the context on the case studies

This set of requirements takes into account the fact that the context during the case study influences the behaviour of the user (Pawson and Tilley, 1997). Results from one evaluation (case study) cannot simply be generalised. The context within each case study is defined by the prevailing conditions during the use of the learning material. Specifically for this purpose, the requirement 'The circumstances during the evaluation are taken into account' is described (requirement rE, Table 3.1). This requirement is not used during the design process, but is described as an *evaluation requirement*: the evaluation of the digital exercise on students' use has to meet this requirement.

The context also includes the learning activity preferences of the students. This could influence the attitude of the students to the learning material: a student who prefers to learn by working in groups or by listening will not be attracted to the digital exercises. Also, the way the student uses the digital exercises could be influenced by the learning preferences (Vermetten *et al.*, 2002). Our learning material aims at Bachelor students enrolled in the curriculum Food Science and Technology who have a learning preference for activities such as answering questions and studying schemes, diagrams and animations.

We realize that several other circumstances could be important to describe the context during the case studies, such as the prior knowledge of the students, the quality of the teachers, prior experiences with computer supported education for both teachers and students, the gender and age of the participants, etc. An endless list of variables could be described and analysed for each study, but we chose to limit the scope of our study.

The quality and user-friendliness of the design

The second set is related to requirements that deal with the way the students perceive the design of the digital exercises. The design can be judged by criteria, such as usability, clarity, and manageability. These judgements give an indication whether students are pleased with the set up of the digital exercises.

The extent to which the digital exercises assist in studying the reader

This set of requirements is related to the main goal of the digital learning material: facilitating the learning of food chemistry. For this, students need to understand the content of the exercises, recognize the content of the exercises in the reader, which is used in the course, and feel that it helps him to remember and understand parts of the reader after completing the exercises.

Table 3.1: The sets of requirements, their evaluation criteria and the corresponding questions or statements in the questionnaires.

set	requirement#	questions or statements	criteria
The influence of the context	The circumstances during the evaluation are taken into account. (rE)##	qE.1: In my opinion other digital learning material (than the digital exercises) is valuable. qE.2. I am satisfied with the desk-space-facilities and computer rooms during the computer classes. qE.3. I am satisfied with the use of Blackboard. qE.4. I am satisfied with the course sequence. qE.5: Overall rate of the course on a scale of 1 (poor) to 5 (excellent).	criteria for 5-point scale*
	The exercises fulfil a need of most of the students in relation to their learning activity preference. (r12)	q12.1. I am someone who learns through (students choose maximally 3 answers from 7 learning activities).	A significant number ($p<0.05$) of students like to learn by the activities 'active answering questions' and 'looking at schemas/diagrams'
The quality and user-friendliness of the design	The exercises are clear. (r1)	q1.1. The exercises are clear (you know what you have to do). q1.2. The formulation of the instructions of the digital learning material was clear and understandable.	criteria for 5-point scale*
	Students perceive the quality of the learning material as good. (rQ)##	qQ.1. The quality of the digital learning material was good.	criteria for 5-point scale*
	The exercises are manageable. (Contain enough hints to work through the exercises.) (r2)	q2.1. With those exercises that I needed hints, the hints were provided. q2.2. With those exercises that hints were provided, the hints were good enough to go through the exercises.	criteria for 5-point scale*
	The exercises are fun to work on. (r5)	q5.1. The exercises are fun to work on.	criteria for 5-point scale*
	Students are motivated not to guess too much. (r10) Students are motivated to repeat an exercise when they do badly. (r11)	q10.1. I used the score as a tool that tells me how well I performed in the exercise: a low score means I did badly, a high score means I did well. q10.2. I used the score as a motivation not to guess too much (except if I did not have another choice). q11.1. When I had a low score I did the exercises again. q11.2. I did the exercises many times until my score for each exercise was close to 10.	criteria for 5-point scale*

Table 3.1 (continued): The sets of requirements, their evaluation criteria and the corresponding questions or statements in the questionnaires .

set	requirement	questions or statements	criteria
Assistance in studying the reader	Content of an exercise is understood after completing the exercise. (r6)	q6.1. At the end of an exercise (after explanation by the computer) I understood the content of the exercise.	criteria for 5-point scale*
	Students are able to recognise the exercises in sections of the reader. (r7)	q7.1. I recognised parts of the exercises in the reader.	criteria for 5-point scale*
	Sections of the reader are easy to remember after completing the exercises. (r8)	q8.1. Parts of the reader were easy to remember after doing the exercises.	criteria for 5-point scale*
	Sections of the reader are easy to understand after completing the exercises. (r9)	q9.1. Parts of the reader were easy to understand after doing the exercises.	criteria for 5-point scale*
Additional value of the exercises	The exercises are used by students on their own initiative. (r4)	q4.1. Tell when you worked on the exercises. q4.2. Estimate how many times you worked on the exercises.	≥ 75% of the students worked outside reserved time and ≥ 75% worked on them more than once
	Students perceive the exercises as valuable. (related to r3)**	q3.1. In my opinion the digital exercises are valuable learning material.	criteria for 5-point scale*
	Students feel they learned much from doing the exercises. (r13)	q13.1. How much did you learn of the different parts of the Food Chemistry course? (Six parts are judged on 5-point scale from nothing to very much)	≥ 75% of the students answer "much" or "very much"
	Students feel that the exercises contributed to their ability to pass the final examination successfully. (r14)***	q14.1A. Estimate (in percentage) how much each part of the course contributes to your ability of doing the final examination. (Your total estimate should add up to 100%.) q14.2A. Estimate how much time you spent on each part of the course. (Estimate the number of hours.)	Average learning efficiency is ≥ 1 (learning efficiency = %contribution / %time)
		q14.1B. The exercises contributed to my ability to answer questions in the final exam. q14.2B. The exercises are efficient for learning: I learned about food chemistry in a relative short period of time.	criteria for 5-point scale*

#: The codes of the requirements are the same codes as used in the design process (Chapter 2).
##: Requirements rE and rQ were not described during the design process. rE is an evaluation requirement (not a design requirement).
*: Average rating should be 4.0 or more AND at least 75% of the students should give a rating of 4 or 5. (5-point scale: 1=totally disagree, 2=partially disagree, 3=neutral, 4=partially agree, 5=totally agree)
**: r3 is ' Students see the digital exercises as a valuable addition to the reader'.
***: questions for r14 differ between case studies, see Table 3.2

The additional value of the digital exercises

The fourth set of requirements is related to the expectation that digital exercises have an additional value compared to other learning materials, such as books, and other learning activities, such as lectures and laboratory classes. The digital exercises are designed to motivate the students and require their active involvement. Every opportunity to present information in the form of a diagram, scheme or animation instead of text has been seized. Therefore, it is expected that students should learn a lot in a relative short period of time. Important for this set of requirements is whether students work on the digital exercises on their own initiative (an indication that students see their value), whether students feel they learned much and whether studying the exercises contributed to their ability to pass the final examination of the course.

The evaluation questions and criteria

In total, twenty-six questions were developed to evaluate the requirements. For the four sets of requirements there are six, ten, four and six questions respectively (Table 3.1). These questions were given to the students through two different questionnaires. The first is a standard course evaluation questionnaire, which is regularly used at Wageningen University. This questionnaire concerns, amongst others, the content, the organisation, the quality of the learning materials, the quality of the teachers, the perceived value of the different educational activities and the way in which information and communication technology has been used for learning support in the course. The second is a specific questionnaire developed for the evaluation of the digital exercises. In Table 3.1 the questions of both questionnaires are listed, from which questions qE.1 to qE.5, q1.2, qQ.1 and q3.1 refer to the questions from the standard questionnaire.

In both questionnaires, most questions are given as statements that need to be judged on a 5-point Likert scale, ranging from 1, meaning 'strongly/totally disagree', to 5, meaning 'strongly/totally agree'. From the answers of all students an average judgement per statement can be calculated. A requirement is satisfied when the average rating for the accompanying statement is at least 4.0 *and* when at least 75% of the students rate the statement with a 4 or 5. Some requirements were not tested with 5-point scale questions, but with multiple-choice questions. Most of these requirements have also a criterion of 75% positive judgement, which is in line with the 75% criterion of 5-point Likert scale questions. See Table 3.1 for specific criteria.

Biases could arise from evaluation questionnaires as used for the current research. Typical method biases are for example those related to acquiescence (agree with attitude statements regardless of content), social desirability (behave in a culturally acceptable and appropriate manner), positive / negative item wording (only using positively or negatively worded statements), or common scale formats (e.g. Likert) and anchors (e.g. agree / disagree) (Podsakoff *et al.*, 2003). It should be noted that the questionnaires are only used to compare the average attitudes of all students between case studies and to compare the average attitudes of all students with the criteria. Therefore, we think that acquiescence bias is not a big issue.

The course structure and organisation in each of the three case studies

The course structure and organization includes components and aspects such as kinds of course topics, number of course credits, number of lectures, number of scheduled computer classes, sequence order of lectures and computer classes, number of laboratory classes, staff/student ratio, relation between reader content and content of the digital exercises. Table 3.2 shows for each of the three case studies the relevant characteristics of course structure and organisation, and also the type of evaluation questionnaire used.

Case studies I and II were both conducted during the Food Chemistry course at Wageningen University in the regular educational setting. The course concerned is a 6 ECTS course (168 study hours). Students had lectures and computer classes, and prior to the final examination in both case studies the course concluded with a laboratory class, all within a time-span of six weeks. After these six weeks there was a week without formal instruction, followed by an examination week. In both case studies I and II a reader, covering the course content, was available to the students. After the final examination the students were asked to fill in the two questionnaires.

With respect to the students in studies I and II, one important difference could be expected between these two groups of students: their assumed prior knowledge of food chemistry when they started working on the digital exercises. Students in case study II had fewer lectures than students in case study I and worked on the exercises on the same day as the lectures were given, which gave them no time to process newly acquired information. In fact, students in case study II were exposed to new information during the exercises. Information, which students in case study I already heard of during the lectures.

Table 3.2: The course structure and organisation in each of the three case studies.

item	case study I	case study II	case study III
Course & Institute	Food Chemistry, Wageningen University	Food Chemistry, Wageningen University	Food Chemistry, Cornell University
Course topics	proteins, lipids, carbohydrates, phenolic components, enzymes	proteins, lipids, carbohydrates, phenolic components, enzymes	water, food colloids, proteins, lipids, carbohydrates, food additives
ECTS* (for course)	6 ECTS	6 ECTS	4.5-6.0 ECTS **
course code	FCH 20806	FCH 20806	FD SC 417
Computer classes (h) for digital exercises	16 h	15 h	Not scheduled
Computer classes (h) for other learning material	16 h	16 h	Not scheduled
Lectures: -introductory -regular -response	- 0 h - 16 h - 0 h	- 5 h - 0 h - 4 h	42 h of lectures.
Laboratory classes (h)	40 h	40 h	Not included (separate class)
Order of lectures and digital exercises	1. lectures 2. computer classes	1. 1-h introd. lecture + 3-h computer class repeated 5 times 2. response lectures***	not specified: use of exercises was voluntary
Relation content reader / lecture notes to content digital exercises	directly related	directly related	only indirectly related
Number of students	34 students	30 students	25 students
Type of questionnaire	Standard and specific	Standard and specific	Only a specific
Questions for r14 (Table 3.1)	*q14.1A* and *q14.2A*	*q14.1B* and *q14.2A*	*q14.1B* and *q14.2B*

*: ECTS is short for the European Credit Transfer System: system of awarding credits for courses according to the criterion of students' workload per course (1 ECTS equals 28 study hours).

**: This is a 3-credit course: 3 contact hours plus 6 to 9 self-study hours per week for 14 weeks (a semester), which makes 126 to 168 hours or 4.5 to 6 ECTS.

***: Response lectures are lectures in which students could ask specific questions or additional explanation on various topics.

The course structure and organisation of case study III was different from the other two. This was carried out at Cornell University (Ithaca, NY, USA), with students taking the Food Chemistry course (3-credit course, comparable with 4.5-6 ECTS). For study purposes an extensive set of lecture notes, which was almost like a textbook, was given to the students. The content of these lecture notes were in some aspects different from that of the reader used at Wageningen University: topics such as water and food additives were included, while topics such as enzymes or phenolic components received less attention. Another important difference in course organisation was that the students' use of the digital exercises was optional, while in case studies I and II the students were obliged to participate in computer classes in which they had to work with the digital learning material. After the final examination, in case study III the students were also asked to fill in a specific questionnaire. The questions were identical to the questions in the specific evaluation questionnaire used at Wageningen University (questions from Table 3.1), with some minor changes related to the course structure and organisation at Cornell University. As shown in Table 3.2, the questions related to requirement r14 were different in each case study.

RESULTS AND DISCUSSION

The results of the case studies are described and discussed on basis of the four sets of requirements as defined before (Table 3.1).

Requirements set 1: The influence of the context on the case studies

Requirements rE 'the circumstances during the evaluation are taken into account' and r12 'the exercises fulfil a need of most of the students in relation to their learning style' are related to the influence of the context. To evaluate the influence of the context on the results of the case studies, questions related to the circumstances during the evaluation (qE.1 to qE.5) and about preferred learning activities (q12.1) were asked to the students.

The appreciation of the circumstances during the case studies

Table 3.3 gives the results of the answers to questions qE.1 to qE.5. These are part of the standard course evaluation questionnaire and were, therefore, not answered by the students in case study III. The responses to these questions indicate that the students in case study I liked the circumstances of the course better than the students in study II. In case study II the circumstances of the course, such as desk-space facilities and the course sequence, are viewed less favourably. It should be noted that the facilities were actually the same in both case studies. We have no satisfactory explanation for the difference. The lower appreciation of course sequence could negatively influence the response of the students to evaluation questions related to the digital exercises.

It was noticed for all case studies that those students who learn by active answering questions also like to learn by looking at visuals, (active) reading and producing visuals (e.g.

pictures, schemes) (data not given). Those who did not choose active answering questions like to listen (attending lectures) and like to learn by (active) reading. For this group of students also "explanation of my questions by others" is a frequently chosen option (data not shown).

Table 3.3: Average response to the questions qE.1 to qE.5 in case studies I (n=28) and II (n=32-41).

questions	case study I		case study II	
	% 4/5	Average (n=28)	% 4/5	Average (n=30-41*)
qE.1: In my opinion the digital exercises for calculations on reactions are valuable learning material.	74	4.0	64	3.7
qE.2: I am satisfied with the desk-space-facilities and computer rooms during the computer classes.	92	4.5	64	3.8
qE.3: I am satisfied with the use of Blackboard.	83	4.4	-	-
qE.4: I am satisfied with the course organisation: 1h lecture, 3h digital exercises, 1h response lecture.	-	-	48	3.6
qE.5: Overall rate for the course on a scale of 1 (poor) to 5 (excellent)	81	3.9	71	3.8

Answers are grouped in percentage of students who responded with a 4 or 5 (1=totally disagree, 2=partly disagree, 3=neutral, 4=partly agree, 5=totally agree) and the average response.
*: 30 students followed the course. The final examination was attended by these students and by some students who did a resit examination, and therefore more students filled in the standard course evaluation questionnaire.

Table 3.4: The learning activity preference of the students in the three case studies (question q12.1). Students could choose at most three activities. For each activity the percentage of students that has chosen that activity are given.

activities: I am someone who learns through …	case study I (n=34)		case study II (n=26**)		case study III (n=16**)	
	%	*p*-value*	%	*p*-value*	%	*p*-value*
A: active answering questions	71	0.001	56	0.18	31	-
B: looking at schemes / diagrams / animations	50	0.26	30	-	56	0.21
C: (active) reading	56	0.09	59	0.09	50	0.37
D: listening (for example a lecture)	44	-	37	-	44	-
E: producing schemes / diagrams / animations	35	-	48	0.45	50	0.37
F: explanation of my questions by others (teacher/student)	32	-	26	-	25	-
G: group discussion / working in a group	18	-	26	-	25	-

*: Calculated with binomial test, test proportion=0.43.
**: Not all students had filled in this questionnaire.

Requirements set 2: The quality and user-friendliness of the design of the exercises

It is assumed that, in the perception of the students, the quality of the design of the learning material is related to characteristics such as usability, ability to motivate, clarity, manageability and ability to enjoy. Results from the questionnaire related to six requirements on how students perceive the design of the learning material are listed in Table 3.5.

According to the criteria for 5-point scale questions the four requirements r1, rQ, r2, and r5 are met, which means that the exercises are clear (r1), the exercises are manageable (r2), the exercises are fun to work on (r5), and the students perceive the quality of the learning material as good (rQ). This gives an indication whether the design and user-friendliness of the exercises is of an adequate quality for the students in each of the three case studies.

Feedback or hints were provided to make the exercises manageable. The results (Table 3.5) from the questionnaire for the two questions that are related to hints (q2.1 and q2.2), show that the hints are applied correctly in the digital exercises for the students in case studies I and II. The lower valuation of the hints by the students in case study III is probably related to the difference in course content. The content of the lectures and lecture notes at Cornell University varies from that of the digital exercises in such a way that these students could need some more hints to be able to answer the questions than the students at Wageningen University or possibly some different hints, since their course content was different, but there are no data that could demonstrate that these students asked for more hints.

Table 3.5: Results for the questions related to the quality of the design for case study I, II and III.

r*	question	case study I		case study II		case study III	
		% 4/5	average	% 4/5	average	% 4/5	average
r1	q1.1: exercises are clear (you know what you have to do)	82	4.3	83	4.2	81	4.3
	q1.2: The formulation of the instructions of the exercises was clear and understandable.	90	4.3	84	4.2	-	-
rQ	qQ.1:The quality of the digital learning material was good.	95	4.4	84	4.2	-	-
r2	q2.1: hints are provided when needed	75	3.8	83	4.1	63	3.6
	q2.2: the hints are useful	85	4.0	83	4.0	69	3.7
r5	q5.1: exercises are fun	88	4.2	73	4.1	81	4.0
r10	q10.1: score tells about performance	85	4.0	50	3.4	63	3.6
	q10.2: score is motivation against guessing	44	2.9	53	3.3	38	2.8
r11	q11.1: low score is motivation to repeat exercise	79	3.9	50	3.3	67	3.4
	q11.2: repeat exercises until maximum score is achieved	38	2.5	28	2.1	47	2.8

Given are the average rating and the percentage of students that rated the question with a 4 or 5 (answers on a 5-point scale: 1=totally disagree, 2=partly disagree, 3=neutral, 4=partly agree, 5=totally agree).
*: r=requirement

The relation between the score and extrinsic motivation

Each exercise is designed with a score, as described before. This score is incorporated in the exercises to motivate students: to discourage guessing and to motivate students to repeat an exercise when getting a low score. The results in Table 3.5 show that in case study I, the students *did* recognise this score as a performance-grader (q10.1), while students in case studies II and III, did not really recognize the score as a performance-grader. The same counts for the question q11.1. In case study I, around 79% of the students agreed with the statement "*the score is a motivation to repeat an exercise when the score is low*". For these students, the score could be recognised as a successful tool to motivate them to perform well, but in case studies II and III fewer students agreed with this statement.

Two factors may explain the lower value of the score in case studiy II as compared to the score in case study I. Firstly tables 3 and 4 show that in case study II the contextual variables such as desktop facilities and computer rooms respectively learning activity preferences have lower values. Secondly the knowledge of the students prior to doing the exercises was most likely very much less in case study II because there were considerably fewer lectures. Due to a lower prior knowledge, students made more mistakes, resulting in a lower score. A low score is not an indication for these students that they performed poorly, but maybe it is an indication for these students that they did not have enough knowledge yet. Students in case study I maybe felt they should have enough knowledge to perform well and therefore they *did* see the score as a performance grader. Students in case study III worked on the exercises of their own free will and could, therefore, not care much about a score or performance.

From the answers on the questions q10.2. and q11.2. in all three studies it is clear that the score itself was not a good motivator for students not to guess too much or to work on the exercises until they did not make any mistakes at all (Table 3.5). It can be concluded that the motivating factor of the score was quite variable per student: some students were motivated by the score and some were not. Just incorporating a score is certainly insufficient to induce an extrinsic motivation for the students to perform well.

Requirements set 3: The extent to which the exercises assist in studying the reader

The reader for the course Food Chemistry at Wageningen University contains a range of relevant chemical concepts. Since students have difficulties to recollect the facts from the reader, the digital exercises were designed in order to stimulate students to work actively with the subject matter. In other words, the digital exercises were designed in such a way that working on the exercises helps students to study the reader. Requirements r6 'content of the exercises is understood', r7 'students are able to recognise the exercises in sections of the reader', r8 'sections of the reader are easy to remember after completing the exercises' and r9 'sections of the reader are easy to understand after completing the exercises' are related to this objective. In Table 3.6 the results from the questionnaire for the questions related to these four requirements are listed.

Table 3.6: Results for the questions related to the assistance in studying the reader for each case study.

r*	question	case study I		case study II		case study III	
		% 4/5	average	% 4/5	average	% 4/5	average
r6	q6.1: content is understood	75	4.0	75	4.1	88	4.3
r7	q7.1: exercises are recognised in reader	76	4.2	73	3.9	75	3.8
r8	q8.1: exercises make reader easy to remember	76	4.0	72	3.9	56	3.6
r9	q9.1: exercises make reader easy to understand	76	4.2	67	3.8	63	3.7

Given are the average rating and the percentage of students that rated the question with a 4 or 5 (answers on a 5-point scale: 1=totally disagree, 2=partly disagree, 3=neutral, 4=partly agree, 5= totally agree).
*: r=requirement

Because it is very likely that the students in case study II did have less relevant prior knowledge when they started on the exercises their learning task will have been larger: they came across more new chemical concepts during working on the digital exercises than the students in case study I. Apart from this the factors mentioned earlier such as less satisfactory desktop facilities in case study II and differences in learning activity preferences may also have been relevant.

Requirements set 4: The additional value of the digital exercises

The digital exercises are designed for the students as an addition to lectures and self-study activities (reading and studying the readers) in order to give them the possibility to work actively with the subject matter. Therefore, it is important to know whether students value the digital exercises as a useful addition. The requirements r3 'students see the digital exercises as a valuable addition', r4 'the exercises are used by students on their own initiative', r13 'students feel they learned much from doing the exercises' and r14 'students feel that the exercises contributed to the ability to successfully pass the final examination' are defined during the design process to ensure that the digital exercises are a valuable addition to the students.

The answers to question q3.1 confirmed that students saw the digital exercises as a valuable addition to the range of learning materials available. In the standard questionnaire students judged all parts of the course, i.e. the reader, the laboratory classes, the teachers and the computer classes. The judgement of the students for the digital exercises can, therefore, be compared with the judgement for other parts, of which the results for the reader, the laboratory part, and the teachers are also presented in Table 3.7. In this perspective, the judgement about the digital exercises was very high in case study I and high in case study II, indicating that students strongly valued the digital exercises.

Table 3.7: Average responses for the standard course evaluation questionnaire in case studies I (n=28) and II (n=30-41).

	case study I		**case study II**	
part of the course	% 4/5	average response	% 4/5	average response
question *q3.1*: In my opinion the digital exercises are valuable learning material.	91	4.6	84	4.1
judgement for reader		3.3		3.5
judgement for laboratory classes		3.8		3.7
judgement for teachers (on average)		3.8		3.7

Answers are grouped in percentage of students who responded with a 4 or 5 (1=disagree, 2=partly disagree, 3=neutral, 4=partly agree, 5=agree) and the average response.

From the answers on questions q4.1 and q4.2 for case studies I and II (Table 3.8), it seems fair to conclude that requirement r4 'students work on the exercises on their own initiative' was met, since 70% of the students worked on the exercises outside the computer classes and 80% of the students worked on some or all exercises more than once. Since these students worked on learning material on their own initiative (i.e. outside the computer classes), they must have seen additional value in the exercises.

Table 3.8: Results for the questions q4.1 and q4.2 related to requirement r4 'students work on the exercises on their own initiative' for case studies I, II and III.

question	**possible answers**	**study I**	**study II**	**study III**
q4.1: Tell when you worked on the exercises.	During computer classes	100%	100%	-
	Outside classes	70%	70%	-
q4.2: Estimate how many times you worked on the exercises.	some exercises, once only	9%	10%	38%
	All exercises, once only	12%	10%	31%
	All at least once, some more often	47%	47%	13%
	All more than once	32%	33%	19%

The results from case study III show clearly that when the digital exercises were optional, students were less inclined to do them. Some other results strengthen this conclusion. From the twenty-five students that were enrolled in this course, five students did not use the digital exercises at all. From the twenty students who used the exercises, 25% did not enter the website for a second time. Furthermore, from the sixteen students who filled in the questionnaire 56% worked on all subjects, 13% worked only on the three main subjects (proteins, carbohydrates and lipids) and 31% worked only on the subject lipids. This preference for lipids was probably because the teacher asked them specifically to work on these lipid exercises. Although students in case study III clearly spent less time on the digital exercises, their opinion about the additional value of the digital exercises was rather positive, as will be discussed later on.

The additional value of the digital exercises is also related to how much students learn from the exercises and whether students feel able to successfully pass the final exam with what they learned from the exercises. For the eight different parts of the course (1. lectures, 2. digital exercises, 3. other digital learning materials, 4. reader, 5. studying own lecture notes, 6. studying notes from digital exercises, 7. laboratory classes, 8. writing report of laboratory class experiments) students were asked to tell how much they learned from these parts (question q13.1). For each part they could choose between “very much”, “much”, “reasonable amount”, “little” and “nothing”. In case studies I and II from “doing the digital exercises”, 68% and 78% of the students learned much or very much, respectively (Table 3.9). For requirement r13 ‘students feel they learned much from doing the exercises’, the criterion is that 75% of the students should have learned much or very much, which means that r13 is not totally met in case study I, but it is in case study II.

Table 3.9: Results for the part digital exercises for the question q13.1 ‘How much did you learn from the digital exercises?’.

question	**answer**	**percentage of students (%)**		
		case study I	**case study II**	**case study III**
Q13.1: How much did you learn from the digital exercises?	Nothing or little	3	7	12
	Reasonable amount	29	15	38
	Much	41	52	25
	Very much	27	26	25

Although the data are not separately shown in a table, it is interesting to note that for the eight different parts of the course in case study I the part ‘reading the reader’ scored the highest

(76% said to have learned much or very much), followed by the digital exercises (68%). In case study II this is the other way around: the digital exercises scored the highest (78%) and the reader scored lower (59%). This difference is remarkable, especially since the time spent on each part is comparable for the two case studies.

Again, the differences between case studies I and II can be explained by the fact that students in case study II had a lower prior knowledge, when starting on the exercises, than the students in case study I. In general students in case study II had to learn more during working on the digital exercises. Students in case study I already learned about various topics during the lectures, hence the information in the digital exercises was not totally new to them.

When comparing the results for question q13.1 of the first two case studies with the results of case study III (Table 3.9) it is obvious that the students from Cornell University learned less from the exercises than the students in case studies I and II, which was to be expected. The content of the food chemistry course at Cornell University is somewhat different from the content of some of the digital exercises, which means that not all exercises are applicable to the situation of these students. In addition, the students worked on the digital exercises of their own accord, which means that most students did not work rigorously on the exercises (see also the results in Table 3.8). Still, 50% of the students in case study 2 said to have learned “much” or “very much”, which is a reasonably good result, in spite of the differences.

Learning efficiency

In case study I, the students were asked to estimate how different parts of the food chemistry course contributed to the ability to pass the final exam (q14.1A) and to estimate how much time they spent on each part (q14.2A). For the first question, students graded for the eight parts of the course (Table 3.10) the percentage they felt that each part contribution to their capability to pass the final examination, taking into account that the total contribution for these eight parts should add up to 100%. Students also indicated how much time (hours) they spent on each part.

From the estimated contribution and estimated time for each part a learning efficiency can be calculated. Efficiency in general is defined as the ratio of the output to the input of any system. Learning efficiency could, therefore, be defined as the ratio of *the percentage contribution of a part to the ability to pass the final exam* to *the percentage time spent on that part*. The learning efficiency for each part was calculated for each student with the following formula:

$$\text{learning efficiency}_{(part)} = \frac{\%\ \text{contribution}}{\%\ \text{time}} = \frac{\%\ \text{contribution}_{(part)}}{\dfrac{\%\ \text{time}_{(part)}}{\%\ \text{time}_{(total)}}}$$

In this formula:

contribution $_{(part)}$ = contribution of a part to the capability to pass the final examination estimated by the student (%)
time $_{(part)}$ = time spent on a part estimated by the student (hours)
time $_{(total)}$ = total time spent for all parts as estimated by the student(hours)

When the learning efficiency is 1 the percentage time and the percentage contribution are equal. The higher the number the more efficiently the time is spent. The average estimated contributions and average of the total time spent on the eight parts, according to the students, are listed in Table 3.10, together with the average learning efficiencies. The learning efficiency is calculated for each student and then averaged. All averages have very large standard deviations.

The learning efficiency of a certain part can only be compared with other parts of the course if they have common educational goals. The first four parts in Table 3.10 are related to activities that are offered by the course. Of these four parts, the digital exercises and the readers have the same learning goals. The lectures are more intended for introduction and the quantitative exercises specifically deal with quantitative understanding of chemical reactions in food.

Table 3.10: The average estimated contribution to the final examination, the average estimated percentage of time spent and average learning efficiency calculated per student for case study I (n=27).

parts	average % contribution	average % time[#]	average learning efficiency [#]	% students with learning efficiency ≥ 1
Attending lectures	11	14	0.8	19
Completing quantitative exercises	9	8	1.5	56
Doing the digital exercises	*21*	*11*	*1.9*	*64*
Reading the reader	30	25	1.4	75
Studying own lecture notes	5	2	4.7	100
Studying own notes from exercises	7	2	5.3	93
Doing the practical part in the laboratory*	9	28	0.4	10
Writing the report for the practical part in laboratory*	7	9	1.1	41

[#]: The average percentage time and average efficiency are both calculated by first calculating this number for each student and then averaging this over all students.
*: The laboratory classes have their own learning goals, which are not examined during the final examination. Separate grades are credited to the laboratory part.

The quantitative exercises are based on a problem based learning paradigm. A description of these exercises falls outside the scope of this article. The second two parts, lecture notes and notes from the exercises, are learning activities that students produce themselves. The last two parts are related to the laboratory classes. These have separate learning goals, mainly laboratory technique and report writing. The skills obtained during the laboratory classes are not examined during the final examination and, therefore, the laboratory classes have a low learning efficiency with respect to the contribution to the final examination (Table 3.10).

For quite a lot of the students (64%), an efficiency rating of the exercises is higher than 1 (average is 1.9). This indicates that requirement r14 is met, since for that the average learning efficiency should at be 1 or more. Moreover, when comparing the learning efficiency for the exercises with reading the reader, the exercises score well. Therefore, with an average learning efficiency of 1.9 and an average contribution of 21%, it can be concluded that the digital exercises certainly have an additional value for the students.

In case studies II and III students were not asked to rate the contribution. Instead, students were asked to rate the statement "*The exercises contribute to my ability to answer questions from the final exam*" on a 5-point scale. Unfortunately, students were not asked to rate this statement for the other parts of the course. Results are shown in Table 3.11, which contains the results of case studies II and III for the questions related to requirement r14.

In case study III we were only interested in the efficiency of the exercises, since other parts of the course (e.g. lectures and readers) were outside our influence. Of the students that filled in the questionnaire 50% agreed that the exercises contributed to their ability to answer questions from the final exam (Table 3.11). So, although the content of the exercises is derived from the reader of the course at Wageningen University, still half the students at the corresponding course at Cornell University could answer questions of their own examination with what they learned in the digital exercises.

In case study III 75% of the students agreed with the statement "*The exercises are efficient for learning: I learned about Food Chemistry in a relative short period of time.*" (q14.2, Table 3.11). This result shows that although the content of courses are not equal, the students learned in an efficient way about Food Chemistry. So, for the exercises it seems that when content is not identical to the content of the course the usefulness for examination is not 100%, but they can still help students learn about food chemistry. This implies that the digital exercises can be a valuable aid for food chemistry courses outside Wageningen University.

Case studies I and III show that the exercises were rather efficient for learning according to the students, but this efficiency as perceived by the students is not a good measure of the ability to pass the final examination successfully. Based on the case study results it will not be possible to provide evidence for the effectiveness requirements.

Table 3.11: Results for the questions related to requirement r14. The questions differ in the different case studies. There were open questions, multiple-choice questions and questions on a 5-point scale.

question / statement	answers	
	case study II	**case study III**
The exercises contribute to my ability to answer questions in the final exam.	3.5 (60%)*	3.3 (50%)*
Estimate the time spend on the digital exercises.	Average 15 hours	-
The exercises are efficient for learning: I learned about Food Chemistry in a relative short period of time.	-	3.9 (75% agreed)*

*: Average of answers on a 5-point scale (1=totally disagree, 2=partly disagree, 3=neutral, 4=partly agree, 5=totally agree), with between brackets the percentage of students that chose 4 or 5 as an answer.

CONCLUSIONS

Despite the differences between the two case studies at Wageningen University and the case study at Cornell University it is clear that the digital exercises are useful to varying degrees in at least three courses with different structure and organisation. Based on the results of the evaluation process carried out in the three case studies it is concluded that most design requirements, that were described during the design process, are met. Therefore, we will continue to apply the design process for food chemistry digital learning material as described in Chapter 2. The design process and the evaluation process together are an example of a design oriented research approach in chemistry education. It has been shown in this paper that this research approach can result in useful digital learning material and in a satisfactory and clearly defined starting point for improvements of education. We expect that this research approach can also be used for development and investigation of other digital learning materials.

The evaluation results show that students' appreciation of the same learning material is different when applied in a different course structure and/or organisation. Therefore, we have carefully described the situation of the case studies, and this is regarded as crucial for an accurate interpretation of the results. From the interpretation of the results, the following preliminary conclusions are described for further research on the effect of the on students' appreciation.

First, when a course consists of several learning activities, the sequential order of these activities influences what students learn from each activity. This is explained by the following. The digital exercises seem to assist the students in studying the reader when the students have already gained some knowledge about food chemistry by attending the lectures. In contrast, students seem to learn more from the digital exercises *without* first attending several lectures. It is reasonable to assume that the knowledge of students prior to starting with the digital exercises will be influenced by previous exposure to relevant information in lectures. Also students who have less relevant prior knowledge invest more time in completing the exercises and thus are likely to learn more from working with the exercises. A second conclusion is about the usefulness of presenting a performance score to the student who does the exercises. This relates the prior knowledge of the student on the topic of the exercise to the value, which a student attributes to the presentation of his performance score in that exercise. It states that low prior knowledge results in a low value attributed by the student to the function that presents a performance score to the student. And third, it is concluded that when the type of activities that are incorporated within the learning material matches with the learning activity preference, the student is more likely to use this learning material and vice versa. This is derived from the differences in use of the digital learning material between the case studies, which are, amongst others, explained by the idea that students will use approaches they like.

Finally, the results of case study III are in keeping with the quite general belief that using digital learning material as basis for a self-study activity, which is not explicitly scheduled, will result in a low use of this digital material, even when the digital material is regarded useful.

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Chapter 4 – Design and Evaluation of Digital Assignments on Acquisition of Quantitative Problem Solving Skills

ABSTRACT

One of the modules in the course Food Chemistry at Wageningen University focuses on quantitative problem solving skills related to chemical reactions. The intended learning outcomes of this module are firstly, to be able to translate food chemistry related problems into mathematical equations and to solve them and secondly, to have a quantitative understanding of chemical reactions in food. Until three years ago the learning situation for this module was inefficient for both teachers and students: a staff/student ratio of 1/25 was insufficient, the level of student frustration was high and many students could not finish the tasks within the scheduled time. To make this situation more efficient and to lower the level of frustration, digital learning material was designed. The main characteristic of this learning material is that it provides just-in-time information, such as feedback, hints and links to background information. The material was evaluated in three case studies in a normal educational setting (n=22, n=31, n=33). The results show that now frustration of students is low, the time in classes is efficiently used, and the staff/student ratio of 1/25 is indeed sufficient. A staff student ratio of around 1/40 is now regarded as realistic.

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INTRODUCTION

Most Master and Bachelor graduates in Food science and Technology move into jobs in (food) companies. In these jobs they are often confronted with situations in which they have to make decisions on the basis of incomplete information, due to limited time available (e.g. strict dead lines). To make an educated guess or a valid decision anyhow, they need to be competent in making quantitative estimations or predictions. Thus, besides being knowledgeable about food science and technology, a graduate also needs quantitative problem solving skills: a graduate should be able to translate a problem into mathematical expressions, to solve these equations and subsequently to transform the outcome into a practical solution. These quantitative problem solving skills are directly related to the ability to make estimations, choose between possible solutions, make predictions, calculate costs/benefits, etc. These skills are for example useful to determine the yield of an isolation, to plan experiments, to optimise food production processes, to predict shelf-life (including storage, packaging), or to quantify the necessary amount of a functional ingredient, enzyme or chemical. Therefore, essential competencies required in jobs occupied by food scientists include these quantitative problem solving skills.

In the course Food Chemistry, which is an introductory course (2^{nd} year Bachelors), quantitative problem solving skills are practiced in classes in which students have to use quantitative approaches to produce solutions for problems that are specific for food science and technology. Until three years ago the learning scenario was as follows: students performed short assignments, which were mainly text based and presented to the student in print, students performed calculations with MS Excel®, and an instructor was present for questions in order to assist students who “got stuck”.

During these classes, most students needed individual instructions from the instructor and many students needed the same instructions, but often not at the same moment. Instructions were content specific, e.g. on how to solve the problem, but also on how to work with Excel. The classes were clearly inefficient for the students, since a substantial part of their time was spent on waiting for instruction and because of this many students could not finish the assignments within the allocated time. Moreover, the teachers often did not want to simply give the answer to the problem right away, but wanted to guide the student in such a way that students came up with the answers themselves. Though this is a good approach from a didactical point of view, it implies that the instructor is occupied with one student for considerable time, while other students are also waiting for support or guidance. In other words, many students required a form of guidance that was more intensive than was provided or the staff/student ratio was too low. Furthermore, it was observed that, because of this, among the students frustration was increasing during each class and motivation was decreasing during the course of this module.

To eliminate these problems the following needs must be taken into account: students need guidance through the tasks, they need feedback on their answers, they need information on how to use certain functions of the computer program Excel, and they need background information on the topics they are working on. Simply increasing the staff/student ratio is too costly and, therefore, it was decided to design a different approach.

With the help of information and communication technology (ICT) information can be provided on demand and just-in-time (JIT) (Kester *et al.*, 2001). This includes links to specific background information, providing hints on how to solve problems and providing feedback on a submitted answer. Furthermore, computer technologies provide possibilities to develop screenrecordings. Screenrecordings are digital audiovisuals, which capture in real time the changes of a computer screen e.g. mouse movements, while a voice-over explains what happens. With screenrecordings one can explain how to work with a certain computer program, which is useful for explaining specific functions of the software program MS Excel®. With ICT as enabling technology, digital learning material on quantitative problem solving skills was designed, to satisfy the needs identified above.

This paper first describes briefly the module on quantitative problem solving skills within the course Food Chemistry. Second, the paper focuses on the design and development of the digital learning material on quantitative problem solving skills based on design guidelines and requirements. Subsequently, a description of the digital learning material developed is presented. Finally, three case studies are described in which the digital learning material is tested against the design requirements. The main goal of the case studies is to answer whether the digital learning material enables a learning situation which is

- efficient in terms of staff/student ratio
- efficient in terms of student effort
- motivating (instead of frustrating) for the student

As can be seen from the first two objectives, the main interest of this design study is to design learning material that makes learning more *efficient* rather than more *effective*. As Clark states 'the instructional designer can and must choose the less expensive and most cognitive efficient way to represent and deliver instruction' (Clark, 1994). This does not mean that care is not taken about *effectiveness*: it will be checked whether students who used the digital learning material do not have lower results for examination questions related to quantitative aspects as compared to students in previous years.

QUANTITATIVE ASPECTS OF THE COURSE FOOD CHEMISTRY

Food chemistry deals amongst others with important (bio-)chemical reactions that occur in food products and agricultural raw materials upon storage or processing. These reactions affect the quality of the food product by influencing the colour, flavour, texture and nutritional / bio-active value. The course Food Chemistry is an introductory course in which students learn about these reactions: how they occur and when and how to prevent or induce them. Besides these qualitative aspects, students also learn about the quantitative aspects of (bio-)chemical reactions in food. Therefore, this course is divided in three modules, in which students acquire content specific knowledge, quantification skills and laboratory skills respectively. For content specific knowledge student attend lectures as well as computer classes. During the latter, students work on digital exercises which are interactive questions that invite students to practice on all kinds of topics within food chemistry (Chapter 2, Chapter 3). These exercises were designed mainly to facilitate the acquisition and use of domain specific knowledge. Laboratory skills are practiced with laboratory classes in which students learn to isolate, modify and analyse food components and to write a report. Quantitative problem solving skills are practiced in classes as described in the introduction of this paper. The main goal of this module is to promote the transfer (application) of knowledge of mathematics, reaction kinetics and reaction equilibrium, which students already acquired in previous courses, to situations in food chemistry. The intended learning outcome of this module is twofold. First, to be able to translate practical food chemistry related problems within Food Technology into mathematical equations, to solve these equations, and to translate the outcomes of the equations into a practical solution. Second, to have a quantitative understanding of the relative importance of bio(chemical) reactions occurring during food processing and storage.

Table 4.1 lists quantitative aspects and chemical characteristics related to these aspects, which are covered by the module of the course on quantitative aspects. The challenge for the student is to take the correct steps needed to translate a food chemistry related practical problem or situation in food industry into the required formulas and mathematical operations.

From these formulas and calculations, chemical characteristic are calculated and subsequently the outcomes are translated into a practical solution. Mathematical operations that students need to use are: deriving equations from definitions, rewriting equations, filling in equations, making a graph, adding a linear or exponential trend line, determining a slope, and performing actual calculations.

Table 4.1: Groups of quantitative aspects and related chemical characteristics that students need to determine in the course food chemistry.

groups of quantitative aspects (with formulas or definitions)	**characteristics to determine**	**example**
group 1: Chemical kinetics (see for example Chang (2000))		
Zero-order reaction: $[A]=[A_0] - kt$ First-order reaction: $[A]=[A_0]e^{-kt}$ Arrhenius equation: $k=k_0e^{-Ea/(RT)}$ Arrhenius plot: $\ln(k)=\ln(k_0) - Ea/(RT)$	• Reaction order • Reaction rate constant: k • Activation energy: E_a • Arrhenius constant: k_0 • Time: t • Concentration: [A], $[A_0]$ • Temperature: T	Determine at what time the vitamin C concentration in a new lemonade drink is degraded for 50% at temperature T_3. One has a table with the vitamin C concentration in time for two temperatures T_1 and T_2.
group 2: Chemical equilibrium (see for example Chang (2000))		
Equilibrium reactions: $K_a=[A^-][H_3O^+]/[AH]$ $pH=-\log([H^+])$ $pK_a=-\log K_a$	• Equilibrium constant: K, pK • Concentration: [AH], $[A^-]$ • pH	Anthocyanins in red cabbage can exist in three forms depending on the pH: A, B and C. You know K_a for A + H → B and K_a for B + H → C. Calculate at a given pH the proportion A, B and C.
group 3: Predicting shelf life (see for example Fennema (1996))		
D-value: heating time necessary to decrease the reaction rate with a factor 10 at that specific temperature z-value: the number of degrees that the temperature has to be increased in order to reduce the heating time 10 times Q_{10}: $Q_{10} = k_{(T+10)}/k_{(T)}$	• Q_{10} • D-value • Z-value • Reaction rate constant: k • Time: t • Temperature: T	For a meal, the lipid oxidation is followed in time by means of the peroxide value. After storage for 4 months at 45 ºC, the peroxide number is so high that the shelf-life has been exceeded. Calculate the shelf-life if the meal would have been stored at 20°C.
group 4: Miscellaneous (see for example Fennema (1996) and Belitz *et al.* (2004))		
Molecular weight - M_w Units enzyme: 1 unit enzyme is the quantity required to obtain 1 micromol product /min °Brix: x °Brix corresponds with x gram saccharose per 100 gram substance Degree of Esterification – DE: % of units of a polysaccharide that are esterified Degree of Polymerisation – DP: numbers of monomeric units in a polymer	• degree of hydrolysis • degree of esterification • time needed for hydrolyses • size of the molecules • sugar concentration • °Brix • M_w • units enzyme	A pectin company using apple marc, wants to lower the DE of the pectins in the extracted apple pulp to 55% in two hours. Determine how many units of enzyme you have to add to 1 kg pectin-extract.

DESIGN OF THE DIGITAL LEARNING MATERIAL

As described in the introduction, ICT provides several opportunities to approach problems with respect to efficiency, frustration and motivation of the classes on quantitative aspects. To take advantage of these opportunities, it was decided to design and develop *digital* learning material.

The design process of the digital learning material is comparable with the design process for digital exercises as described previously in Chapter 2. In short, the design process starts with the description of design guidelines and design requirements based on theories of learning and instruction (Anderson, 1995; Keller, 1983; Kester *et al.*, 2001; Kirschner, 2002; Merriënboer, 1997; Sweller *et al.*, 1998), of Food Chemistry subject matter (Belitz *et al.*, 2004; Chang, 2000; Fennema, 1996) and learning goals, and of user interface design (Evans *et al.*, 2004; Marcus, 1997). The requirements define operationally the goals of the design and the variables to which the requirements refer can be measured. The requirements are used to evaluate the learning material and are, therefore, described in the evaluation section of this paper (Table 4.3). The design guidelines for the digital learning material are summarized in Table 4.2. More extended information about the guidelines and the theories, on which the guidelines are based, is given in Chapters 1 and 2 of this thesis.

Table 4.2: Design guidelines for designing and developing the digital learning material on quantitative aspects.

design guidelines based on …	design guidelines*
Cognitive load theory	g1: (Re)activate prior knowledge g2: One new concept per task (adequate sequencing of information) g3: Present information just in time (JIT) g5: Divide the problem into subproblems with subgoals (assist in acquisition of schemata)
Motivation of students	g7: Gradually build up the difficulty g10: Show importance of the subject matter g25: Give the student a feeling of independence
Activation of students	g11: Provide challenging tasks g17: Provide hints/feedback g26: Provide essential background information
(Food) Chemistry subject matter and learning goals	g19: Incorporate the learning goals. g20: Be accurate in the subject matter. g21: Be consistent in the subject matter.
User interface design	g22: Assist in navigation. g23: Use colour in a functional way.

*: The number of each guideline in Table 4.2 is related to the same guidelines in Chapter 2, Table 2.1.

The design guidelines based on the cognitive load theory (Sweller *et al.*, 1998; Kirschner, 2002) aim at the optimisation of the cognitive load of the students during working with the digital learning material. The problems that students have to deal with in the module on quantitative aspects can be regarded as transformation problems. Research on rather simple transformation problems suggests that experts and novices tend to apply different approaches (Larkin *et al.*, 1980). This is visualized in part A of Figure 4.1. Experts work forward, from the initial state of the problem to the goal state (which is, according to Larkin and co-workers (1980), something they only do on easy problems). Novices solve the problems by working backwards from the goal state to the initial state. This approach may induce a high cognitive load on the students, as explained by Larkin and co-workers (Larkin *et al.*, 1980): 'Novices (…) seem to require goals and subgoals to direct their search. The management of goals and subgoals – deciding what to do next – may occupy considerable time and place a substantial burden on limited short-term memory'. So, in order to reduce the cognitive load, students could be presented with subgoals, as presented in part B of Figure 4.1. The subgoals show students a possible solution on how to solve the problem.

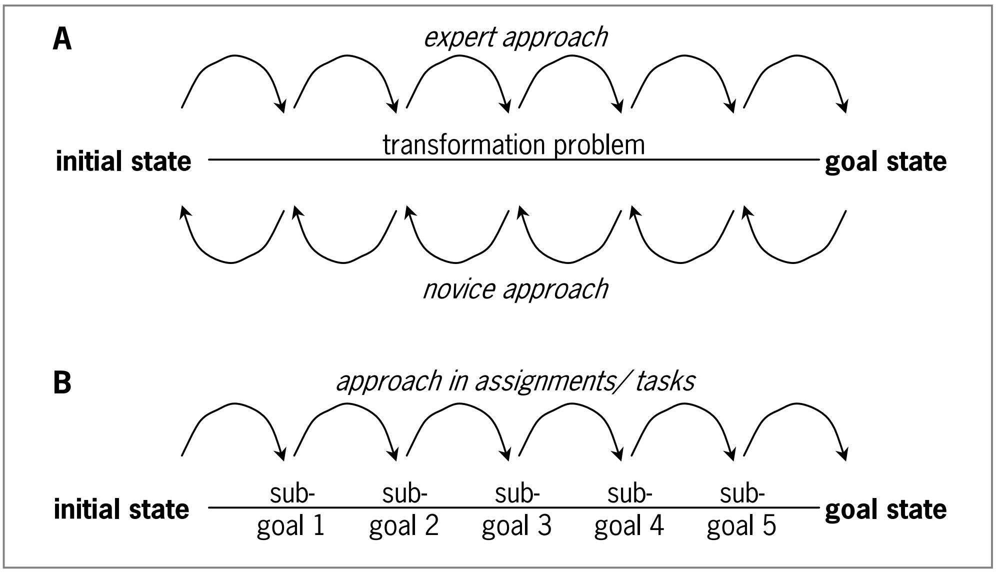

Figure 4.1: **A:** Visualization of the approach experts could use to solve a transformation problem, compared to the student approach (Larkin *et al.*, 1980).
B: The approach that students follow during an assignment / task.

Furthermore, the attention of the students is easily drawn towards mental processes that do not facilitate learning, such as searching for (additional) information or trying to work with an unfamiliar function of Excel (typical instance of extraneous cognitive load, (Sweller *et al.*, 1998)), rather than towards mental processes that support the acquisition of new knowledge and new skills. In this way, a cognitive overload arises easily. With the help of a few guidelines digital learning material can be designed in which the cognitive load is lowered for mental processes that do *not* result in learning, while the mental processes that *do* result in learning are induced. These guidelines are (Table 4.2) reactivating prior knowledge (g1), sequencing the information adequately (g2), presenting necessary information just in time (g3) and dividing the problem into subproblems by providing subgoals as shown in Figure 4.1B (g5).

Guidelines based on motivation of students are related to confidence and relevance (Keller, 1983): induce confidence by gradually building up the difficulty (g7) and giving students a feeling of independence (g25) and incorporate relevance by showing importance of the subject matter, which is in this case showing the usefulness of the quantitative approach (g10).

Guidelines based on activation of students (a.o. Anderson, 1995; Merriënboer, 1997) are mainly based on how the learning material can activate students. The tasks should be challenging to active students (g11) (which is also a matter of motivation). Furthermore, providing hints and feedback (g17) and (links to) background information (g26) keeps the students active whenever he/she is stuck in a task.

There are guidelines on food chemistry subject matter (e.g. Belitz *et al.*, 2004; Chang, 2000; Fennema, 1996) and the learning goals of the course, to provide an accurate content (g20), a consistent content (g21) and a content that is relevant for the learning goals (g19). Finally, there are some guidelines on user interface design (e.g. Marcus, 1997), to make sure the design is clear and understandable (g22, g23).

A few prototypes of the learning material were developed according to the design guidelines and tested in a formative evaluation with 20 bachelor students Food Science and Technology in the normal educational setting. According to the results from this formative evaluation, various improvements and adjustments were made to the learning material. Subsequently, the digital learning material is evaluated in three case studies (A, B and C), as will be described in the evaluation section.

DESCRIPTION OF THE DIGITAL LEARNING MATERIAL

The digital learning material consists of three parts:

- *assignments* : deals with authentic problems related to food chemistry
- *background information* **:** on how to calculate several characteristics (Table 4.1)
- *introduction to Excel* : introduces those functions of MS Excel® students will need

The assignments

Six assignments have been developed, each containing about 10 tasks that guide students through the process of translating practical problems within food chemistry to mathematical equations and solving these equations.

Figure 4.2 shows the generic structure of an assignment. An assignment starts with a short introduction of the situation: each assignment is built around a conceivable situation in food science or food industry. For example, the student plays the role of a researcher who has the task to solve a problem in a company. The calculations in the assignment lead to a solution of the problem or to a clarification of the situation, which shows the usefulness of the quantitative approach (and the calculations) to the students (guideline g10).

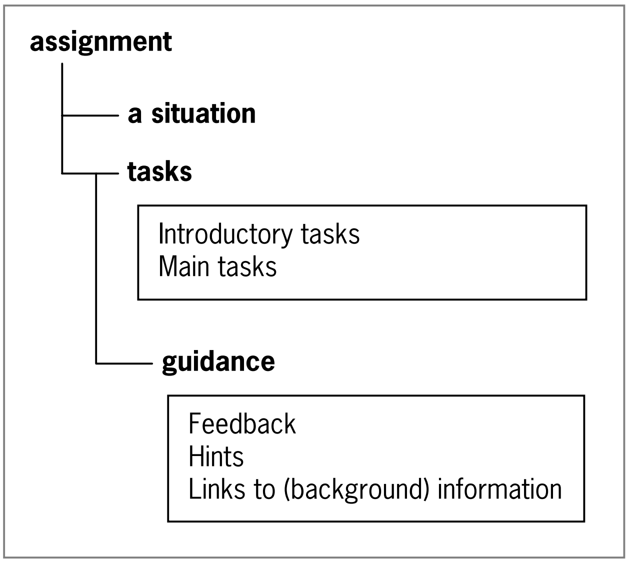

Figure 4.2: The general structure of an assignment: a situation with tasks containing guidance.

The introduction is followed by one or two introductory tasks, which require the application of basic knowledge necessary to understand the situation of the assignment, and have the objective to activate (make available) prior knowledge (guideline g1). This is important for learning, since the availability of relevant prior knowledge improves the learning capacity (Biemans, 1997).

The introductory tasks are followed by the main tasks. In these tasks students have to perform the translation from the practical situation (problem) into mathematical operations and interpret the results from these operations. As explained in Figure 4.1, in order to reduce cognitive load, the goal of the assignment should be divided into subgoals. Therefore, a problem is often decomposed into smaller problems, which means that for example one calculation is divided into 2 or 3 tasks in a logical sequence. The first task of such a series of tasks starts with translating the problem into possible mathematical equations. In the next task, the student performs the first part of the calculation, followed by another task that concludes the calculation. In this way the information is adequately sequenced (g2), students are assisted in the acquisition of schemata on how to solve such a problem (g5) and the difficulty is gradually built up (g7).

A task always consists of one of the two question types 'fill in the blank' or 'multiple choice'. The 'fill in the blank' approach is mainly used when students have to calculate a certain number, which can be filled in. Figure 4.3 gives an example of a 'fill in the blank' question type. Multiple choice questions are used for the introductory tasks or for tasks in which students are asked to make a choice, for example which mathematical operation the students need to use.

During the tasks students are guided in three ways (Figure 4.2): with feedback, with hints (guideline g17) and with specific background information (guideline g26).

Feedback can be defined as the return of information to reflect on the result of a process or activity. Feedback is, therefore, used to give information *according* to the answer of the student, for example "This number is too low. Did you remember that you have to give your answer in 'mg' instead of 'g'?".

When solving a task in which the student has to take several sequential steps, the task is often supported with hints. When the student gives a wrong answer, the student is provided with such a hint. Students can also ask for a hint themselves, at any moment. The hints have a logical order. The order of the hints corresponds with the order of the steps to be taken as a possible way of reasoning on how to handle the task (guideline g5). In other words, the goal of the task is divided into subgoals to lower cognitive load (Figure 4.1). First an overall hint is given, for translating the situation into a (possible) approach. After following up all hints, the student should be able to complete the task. In other words, hints provide students the possibility to tackle the problem on their own, even when at first glance they do not know how to solve the problem. This gives the students a feeling of independence (guideline g25). An example of a task with an array of hints is given in Figure 4.3. In this case, the student has been provided with 6 hints (shown in the second screen dump) about calculating k with the use of the Arrhenius equation. These hints are indispensable for students who have difficulties with completing the task.

Hyperlinks are used to guide students to specific background information. Figure 4.3 shows two links to *Help with Excel* and two links to *Help with Reaction kinetics*, which lead to background information that can be useful for the activities that the student has to undertake in this task.

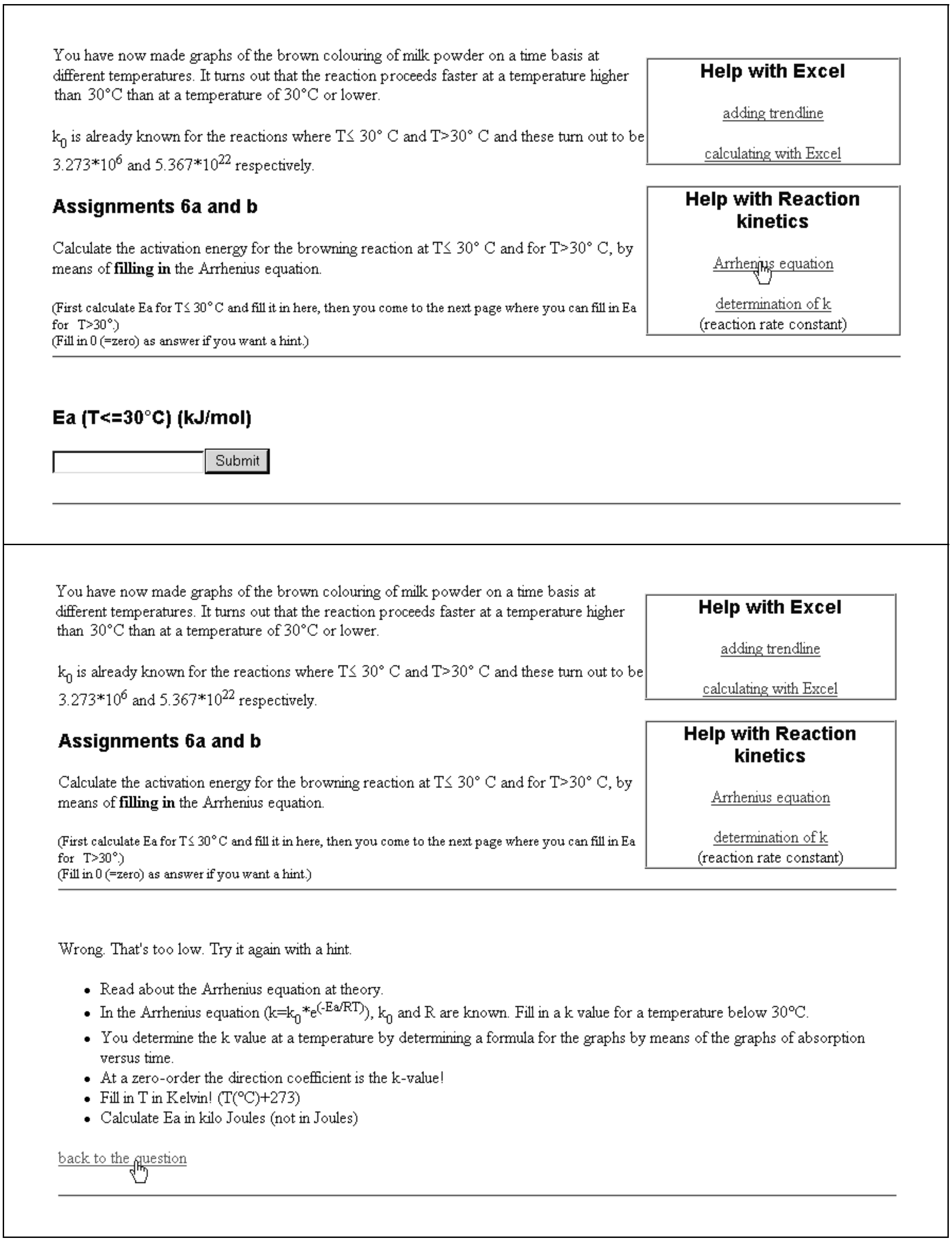

Figure 4.3: An example of a task, with links to background information. After filling in a (wrong) answer (first screen dump), the student gets feedback and a hint (second screen dump). In this case the student already asked for a hint for 6 times (6 hints are shown).

Background information

The assignments mainly deal with applying mathematical models and operations to chemical reactions in relation to the quantitative aspects mentioned in Table 4.1. Students have learned about these aspects in former courses: they know for instance about reaction orders and the Arrhenius equation. For students it is still troublesome to apply these quantitative aspects to solve quantitative problems in food chemistry related situations. The background information is, therefore, not explaining the theory behind these quantitative aspects, but explaining how to use these aspects in mathematical models and operations in calculations on chemical reactions. The background information contains visuals, worked out examples and point-by-point explanation of applied mathematical operations.

Introduction to Excel

The learning material was tested in three case studies: study A, B and C. In both case studies A and B teachers still noticed difficulties in using the Excel program (MS Excel®). Although screenrecordings demonstrating several functions of Excel had been developed to show the students how to use these functions, in both case studies (A and B) only a few students took time to watch these screenrecordings. The assignment 'Introduction to Excel' was subsequently developed to solve this problem. This introduction assignment consists of 5 parts, successively explaining how to introduce numbers into Excel, how to make a graph, how to add a graph to an existing graph, how to add a trendline to an existing graph (linear and exponential), and how to make calculations with the use of several mathematical functions. Completing this introductory assignment will take the student about 15 minutes.

Each of the 5 parts starts with a screen-recording about a function of Excel, followed by a task. The subject of the task matches the content of the screenrecording. Figure 4.4 holds a screen dump of such a screenrecording. The screenrecording shows the screen of someone who is working with Excel, while a voice-over is explaining the events on the screen.

The introduction is offered as 'assignment 0' before the students enter the actual assignments. The aim of this introduction is that before students start working on the actual assignments they have already come across the functions of Excel they will use in the subsequent assignments. In this way, they can focus their attention more directly to the actual calculations and reactions (guideline g1). It is good to be aware of the fact that a group of students is normally quite heterogeneous with respect to their prior Excel skills. This means that only those students who lack prior knowledge about Excel or whose prior knowledge is not active enough, will benefit from this introduction to Excel.

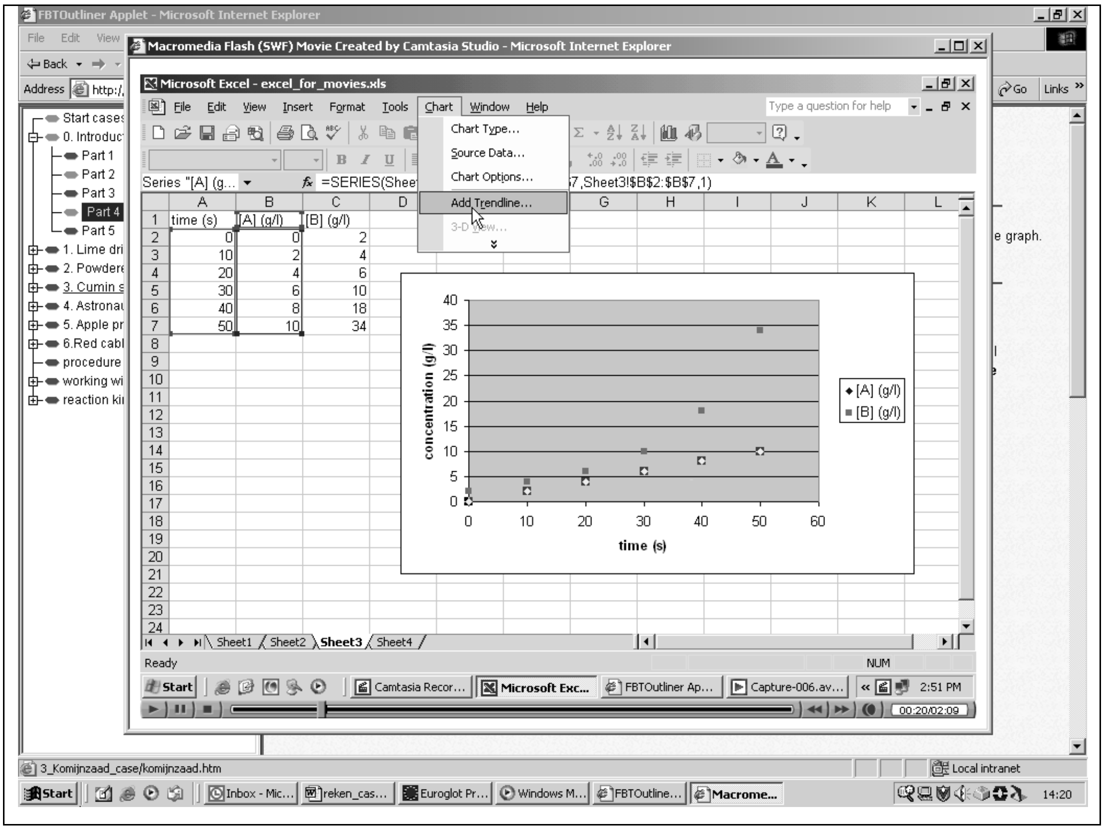

Figure 4.4: A screen dump of the website with on top a screen-recording about Excel. At the moment, the instructor is in the middle of explaining how to add a trendline to the graph.

EVALUATION

The main goal of the design of the digital learning material is to provide an efficient learning situation for both students and staff, that is also motivating for the students. This main goal is translated into 4 sets of requirements: designing learning material which provides a learning situation which is efficient (1), in which the frustration of students is low (2), in which students can work on their own (3) and in which students see the usefulness of performing quantitative analyses and is motivating for students (4). These sets of requirements of the digital learning material are listed in Table 4.3.

On the basis of the design requirements of Table 4.3 the digital learning material was evaluated. By means of a questionnaire, students were asked to rate statements, which were directly related to the requirements. Students could rate each statement on a 5-point scale (1-totally disagree, 2-partly disagree, 3-neutral, 4-partly agree, 5-totally agree). A requirement is satisfied when the average rating for the accompanying statement is at least 4.0 *and* when at least 75% of the students rate the statement with a 4 or 5. This average rating of 4.0 is based on the fact that when students rate the statement with a 4 or 5 they have a positive attitude with respect to this statement, so at an average judgement of lower than 4.0 students' attitude is more neutral (or even negative) than positive. Furthermore, to make sure that the vast majority of the students are positive with respect to a statement, at least 75% of the students should agree with it (rate a 4 or 5).

Table 4.3: Requirements related to the goals of the design of the learning material, mapped in four sets of requirements

sets of requirements	**design requirements in each set**
Learning situation is efficient	Teachers can easily supervise 25 students. All students can finish the assignments in the scheduled time.
Frustration by students is low	Students agree that the website has a clear structure. Students agree that the degree of difficulty is just right. Students agree that the supervision is good. Students agree that the background information is JIT accessible and sufficient.
Students can work on their own	Students agree that the assignment 'Introduction to Excel' is useful. Students agree the screenrecordings about excel are useful. Students agree the background information is useful. Students agree the hints are useful. Students agree the hints are clear. Students agree the feedback/hints are enough to go through the tasks.
Useful / motivating for students	Students agree that the assignments are fun to work on. Students agree that the tasks are instructive Students agree that the tasks show usefulness of the calculations Students agree that the tasks give insight on how to use reaction kinetics, etc. Students agree that the context is motivating Students agree that the context is useful.

Three case studies

The digital learning material has been evaluated in three case studies, all during the regular course Food Chemistry at Wageningen University. The studies differ slightly:

- *case study A* : 22 students worked individually on the assignments during 4 computer classes, each of about 4 hours. The researcher was present, acting as a teacher who was around for questions. After finishing the last computer class students completed a specific evaluation questionnaire and at the end of the complete Food Chemistry course students completed a standard course evaluation questionnaire from Wageningen University. Statements in the specific questionnaire were related to the design requirements (Table 4.3), whereas the statements in the standard course questionnaire were more general statements, for example statements related to the course in total.

- *case study B* : The digital assignments in this study were similar to the ones in study A. In total 31 students worked individually on the assignments during 4 computer classes, each of about 4 hours. During these classes, a teacher was around for questions. The questionnaires were the same questionnaires as used in study A.
- *case study C* : The digital assignments in this study were the same as the digital assignments in studies A and B, but then translated in English and an additional assignment 'Introduction to Excel' was presented. Most of the in total 33 students worked individually on the assignments (some worked in pairs) during 4 computer classes, each of about 4 hours. During these classes, a teacher was around for questions. The same questionnaires as in studies A and B were used, with some additional statements about 'Introduction to Excel' in the specific questionnaire.

RESULTS AND DISCUSION OF THE EVALUATION

The results of the three case studies for the specific evaluation questionnaire and for the standard evaluation questionnaire from Wageningen University are listed in Table 4.4 and in Table 4.5, respectively. From the results for the questionnaires it can be concluded that the digital learning material satisfies almost all design requirements listed in Table 4.3. The results will be discussed in relation to the sets of requirements of the digital learning material.

Set of requirements: Learning situation is efficient

Teachers are satisfied with the supervision: they can now easily supervise 25 students and probably one teacher can even manage the supervision of 40-50 students if all students are situated in the same computer room. Furthermore, it is noticed that almost all students can finish the assignments in the time scheduled. Thus, it can be concluded that the digital learning material provided an efficient learning situation for both the students and the teacher without having to increase the staff/student ratio.

In terms of effective education, the examination results show that the performance of the students in the quantitative part of the final examination is the same as the performance of the students in the old learning situation (results not shown).

Set of requirements: Frustration by students is low

The results of the statements related to the requirements on the frustration of students (Table 4.4) show that students are satisfied with the digital learning material. Also, students agree that supervision was good during the computer classes (Table 4.5).

Table 4.4: Results from the specific questionnaire for the three case studies A, B and C.

		average results for case studies A, B and C (total n=85)	
set of requirements	**requirement / statement in questionnaire**	average [1]	% 4 or 5 [2]
Learning situation is efficient	One teacher can easily supervise 25 students.	True	-
	All students can finish the assignments in the scheduled time.	True	-
Frustration by students is low	Website has clear structure.	4.7	98%
	Degree of difficulty is just right.	4.3	87%
	There is enough JIT information.	4.3	89%
Students can work on their own	'Introduction to Excel' is useful. [3]	3.6 (n=32)	63% (n=32)
	Screenrecordings about excel are useful. [4]	3.8 (n=58)	62% (n=58)
	Background information is useful. [5]	4.7	94%
	Hints are useful.	4.5	95%
	Hints are formulated clearly.	4.3	88%
	Feedback is enough to go through the tasks.	4.1	83%
Useful / motivating for students	Digital assignments are fun to work on.	4.3	95%
	Tasks are instructive	4.5	97%
	Tasks show usefulness of calculations.	4.4	93%
	Tasks give insight on reaction kinetics.	4.6	97%
	The context is motivating.	4.6	93%
	The context is useful.	4.4	91%

[1]: Average of the response of all students on a 5-point scale: 1=totally disagree, 2=partly disagree, 3=neutral, 4=partly agree, 5=totally agree.
[2]: % of students that judged the requirement with 4 (partly agree) or 5 (totally agree).
[3]: In studies A and B 'Introduction to Excel' did not exist.
[4]: On average each student watched 3 our of 5 screenrecordings. The differences between students and between studies are large: ranging from watching only one screenrecording to watching two times all screenrecording.
[5]: On average each student used the background information 5 times per assignment.

During the classes, students seem to work without frustrations: neither complaints nor puzzled faces were noticed and students did not need to wait long if they asked for help from a teacher. Taking all this into account, it can be concluded that frustration of students is low during working on the digital learning material.

Table 4.5: Results from the standard evaluation questionnaire at Authors' University from case studies A and/or B and/or C.

statements from standard evaluation questionnaire	average rating [1]	% 4/5	n [2]
Digital assignments are valuable learning material	3.8	68	n=75
Quality of the ICT material was good	4.1	82	n=47
The formulation of the ICT material was clear and understandable	4.3	86	n=91
Supervision during the computer classes was good	4.3	88	n=44
Overall rating of the complete Food Chemistry course (1=poor, 5=excellent)	3.8	75	n=91

1: Average of the response of all students on a 5-point scale: 1=totally disagree, 2= partly disagree, 3=neutral, 4=partly agree, 5=totally agree.
2: Each year some statements were changed, so some statements were not judged in all studies.

Set of requirements: Students can work on their own

To make sure that the students can work on their own on the assignments, students need to be able to access information that guides them through the tasks whenever there is a need. Moreover, this information should be useful to the students. The results on the statements related to this goal show that the information provided is useful to them, except from the screenrecordings about Excel and the assignment 'Introduction to Excel' (Table 4.4). A more close examination of the results related to the screenrecordings indicates that some students really feel supported by the screenrecordings and some really do not (results not shown). The latter group indicates that they already knew how to work with these properties of Excel. In case study C, 80% of the students gave the same judgement for 'Screenrecordings about Excel are useful' as for 'Introduction to Excel is useful'. This indicates that those students who are positive about the introduction assignment are also positive about the screenrecordings and vice versa. Almost all students watched the screenrecordings in case study C, which indicates that the added 'assignment 0' is useful to gain the attention of the students to the screenrecordings. While the students in case study C were working on assignment 0, both the students and the teacher could give all their attention to those features of Excel that students will need in the following assignments. Subsequently, while working on assignments 1 to 6, the number of questions about Excel was lower in case study C compared to case studies A or B. The 'Introduction to Excel' seems, therefore, an efficient way to make students aware whether or not they are competent enough in working with Excel and to prepare them for the assignments.

As an additional question we asked students to rate the statement 'Supervision is necessary', to which 79% of the students agree (average on a 5-point scale is 3.9, not shown in Tables 4.4 and 4.5). When taking into account that the following requirements are met in each of the three case studies: 'feedback is enough to go through the tasks', 'hints are useful and clear', 'there is enough JIT information' and 'supervision during the computer classes was good', we have to conclude that although students indicate that they have enough information to go through the assignments, they still prefer to have a teacher around for questions. It became clear from the computer classes that from the few questions students asked to the teacher the major part was not related to the content or on 'how to solve the problem', but was most often related to inaccuracies or mistakes made by students in their calculation. It is virtually impossible to take account of all possible mistakes a student can make in his/her calculations within the feedback or the hints of the learning material. To investigate whether students truly feel if they need a teacher around, this question need to be asked to students who worked on the assignments without the presence of a teacher.

Set of requirements: assignments are useful and motivating for students

The results of Table 4.4 for statements related to motivation show that students consider the digital learning material motivating. The results for statements related to usefulness also show that students consider the digital learning material useful (Table 4.4), although in the standard evaluation questionnaire the statements 'digital assignments are valuable learning material' was rated with an average of 3.8 (68% of the students agreed) (Table 4.5). This evaluation questionnaire was completed after the examination, while the specific evaluation questionnaire, of which the results are shown in Table 4.4, was completed after finishing the computer classes. This is an indication that, since after the examination students were less positive about the digital assignments, the examination questions did not totally satisfy the expectations of the students after working with the digital assignments. The examination questions were also divided into sub-questions, just as the assignments are divided into tasks, but the size of the tasks of each examination sub-question was larger than that of the tasks in the digital assignments. There is a possibility that students still feel not competent enough to solve the examination sub-questions.

CONCLUSION

According to the results of the three case studies, it is fair to conclude that the digital learning material was designed in such a way that it enables a learning situation that is efficient for students and efficient for staff with a staff/student ratio of 1/25. Moreover, we are confident that we can even provide a learning situation with a staff /student ratio of about 1/40. The students demonstrated that they were motivated to work on the assignments and also no signs of frustration could be observed.

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Chapter 5 – Design and Evaluation of Digital Assignments on Research Experiments

ABSTRACT

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 find 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.

Submitted as 'Design and Evaluation of Digital Assignments on Research Experiments within Food Chemistry' by Julia Diederen, Harry Gruppen, Rob Hartog, and Alphons G. J. Voragen.

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 goal *learning the scientific content* is supported by readers and/or books, lectures and activities such as exercises in which students can process the concepts and theories. 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 classes in which students perform experiments or watch experts performing experiments in a laboratory environment.

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). Several researchers have given arguments why it is important to teach students experimentation skills. Laboratory classes are useful for (Gooding *et al.*, 1989; Justi and Gilbert, 2002; Kirschner and Meester, 1988; Meester and Kirschner, 1995; Polanyi, 1969):

- 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 because 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 (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 goals 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 goals need to be achieved 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 (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 and co-workers (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 (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 (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

As explained in the introduction of the chapter, 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 5.1 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 and co-workers (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; Roberts, 2001; Johnstone and Al-Shuaili, 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.

The final list of learning objectives (Table 5.1) 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.

Table 5.1: 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

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

From the learning activities related to science education used within food chemistry, the learning activity 'following lectures' is regarded to be cheap for the educational organisation. Learning activities in computer classes are regarded to be more expensive than lectures. For computer classes, in which students work on computer based learning material, costs are high for the development (or purchase) of the computer-based learning material and also perhaps the computer facilities are more expensive than lecture facilities. Laboratory classes are regarded as a more expensive learning activity than computer classes and lectures, since laboratory classes have high costs of assistance, require more input from technical staff, and use expensive materials (chemicals, glassware, equipment, etc.). Moreover, practical rooms are regarded as more expensive than lecture and computer rooms, since the costs per square meter per student are higher than for lecture and computer rooms.

Cognitive efficient

As explained, the learning objectives from Table 5.1 are in general supported with laboratory classes. Since laboratory classes are regarded as expensive and do not sufficiently support achievement of all these learning objectives in a cognitive efficient way, it is interesting to investigate whether these learning objectives could also be attained with other learning activities.

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'. 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 chapter.

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 5.1.

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 goals 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

As mentioned above, with the digital assignments on research experiments students should be able to practice skills related to the learning objectives 'being able to formulate hypotheses', 'being able to design experiments' and 'being able to interpret experimental data' and students should come across possible pitfalls that can occur during laboratory work. These three learning objectives are related to the science education goal *learning the scientific methodologies*.

The intended assignments have three goals:

- they provide a situation in which students can develop the three learning objectives.

- 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 chapter 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 in Chapter 2 of this thesis. Table 5.2 lists the design guidelines for the assignments. These design guidelines will be described now in detail.

Table 5.2: 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 chapter a reference to its number as given in this table is provided.

Instruction style

Domin (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 and problem-based styles, the procedures that students follow are student generated, while in the other two styles students use a given procedure. Furthermore, the inquiry and discovery styles both have an inductive approach (the observation of specific situations to learn the general principles), while the other two styles have a deductive approach. At last, the inquiry style holds an undetermined outcome, while the other styles have predetermined outcomes.

The inquiry laboratory style gives students the opportunity to engage in authentic investigative processes and has been proven to be beneficial in promoting positive attitudes towards science and in fostering critical thinking (Domin, 1999b). Furthermore, the following cognitive skills are related to the inquiry instruction style: hypothesizing, explaining, criticizing, analyzing, 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 5.1. The research method in Figure 5.1 is in the first place 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.

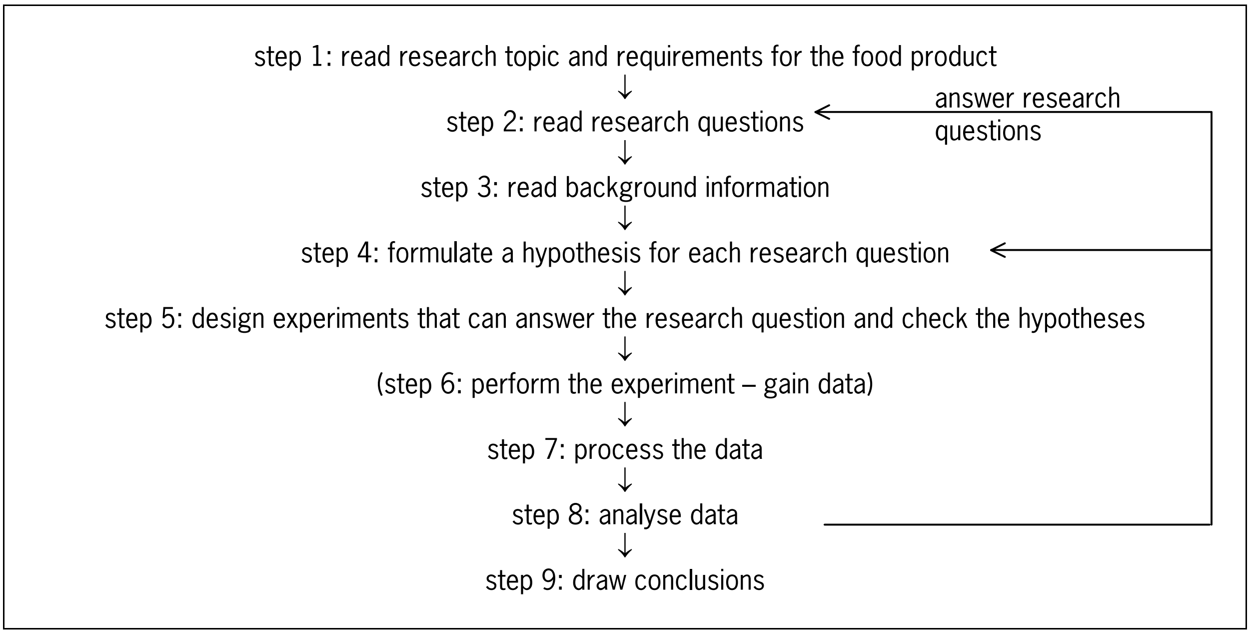

Figure 5.1: Research method for the assignments on research experiments.

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 first learning objective 'being able to formulate hypotheses' (Table 5.1). Step 5 is related to the second learning objective 'being able to design experiments' (Table 5.1). 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 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 5. The steps 7, 8, and 9 are related to the fourth learning objective 'being able to interpret experimental data' (Table 5.1).

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 his or her desk, this activity is strongly related to 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. Making a design for experiments is very strongly related to manual activities that people perform in the laboratory, while thinking of for example a research question has nothing to do with the experiments yet. 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 5.2 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 chapter.

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. First, the research performed in this field and the activities performed during research will be explored. 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 5.3. The emphasis of research within 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 5.4). The main experimental activities that food chemists perform are isolation of components, characterisation of components and modification of components or applications within food systems.

Table 5.3: Research performed within the field of food chemistry

the research area of food chemistry (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

Table 5.4: 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.

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 5.5 shows that the research topics of the assignments are related to all experimental activities from Table 5.4.

Table 5.5: The description of the research topic of the assignments and the relation with the experimental activities in the field of food chemistry

	research topic of the assignment	**experimental activities** (Table 5.4)
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.

Incorporation of the research method

The research method as represented in Figure 5.1 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 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 in order to give just-in-time access to information about this specific term. For example, if a research question contains the term 'gel structure' a student can get the information from the library about gel structure by clicking on that specific term. This saves time for searching for information and also encourages students to read the information. In former evaluations with other digital learning material 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. Mogavero *et al.*, 1969; Morgan, 1995; Beauchamp and Youssef, 1998; Baker and Dunbar, 2000). 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 brainstorm was performed with a number of experienced researchers to see which steps one takes when designing experiments. The following routine was deducted from this brainstorm:

- first define in short what experiments are needed to answer the research question
- then see whether some experiments can be combined
- choose which methods, equipment and chemicals you are going to use to perform the experiments
- write down a scheme of the experiments, a kind of work plan

To make this routine suitable for education it needs some revision, which resulted in a design process consisting of four phases as described in Table 5.6. For assignments 1 and 2, students perform the phases A - D in the laboratory environment of the assignment. The Figures 5.2A to 5.2D 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 experimental steps for the experiment by selecting the steps with a mouse click (Figure 5.2A). 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 5.2B). Experiments that can be combined should follow up on each other. 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 5.2C). To be able to make a choice between the different methods, in front of each method an information button is provided. When clicking on this button a window opens that contains all necessary information (principle, technique, application, results, limitations, and an example) of that method.

Table 5.6: 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.

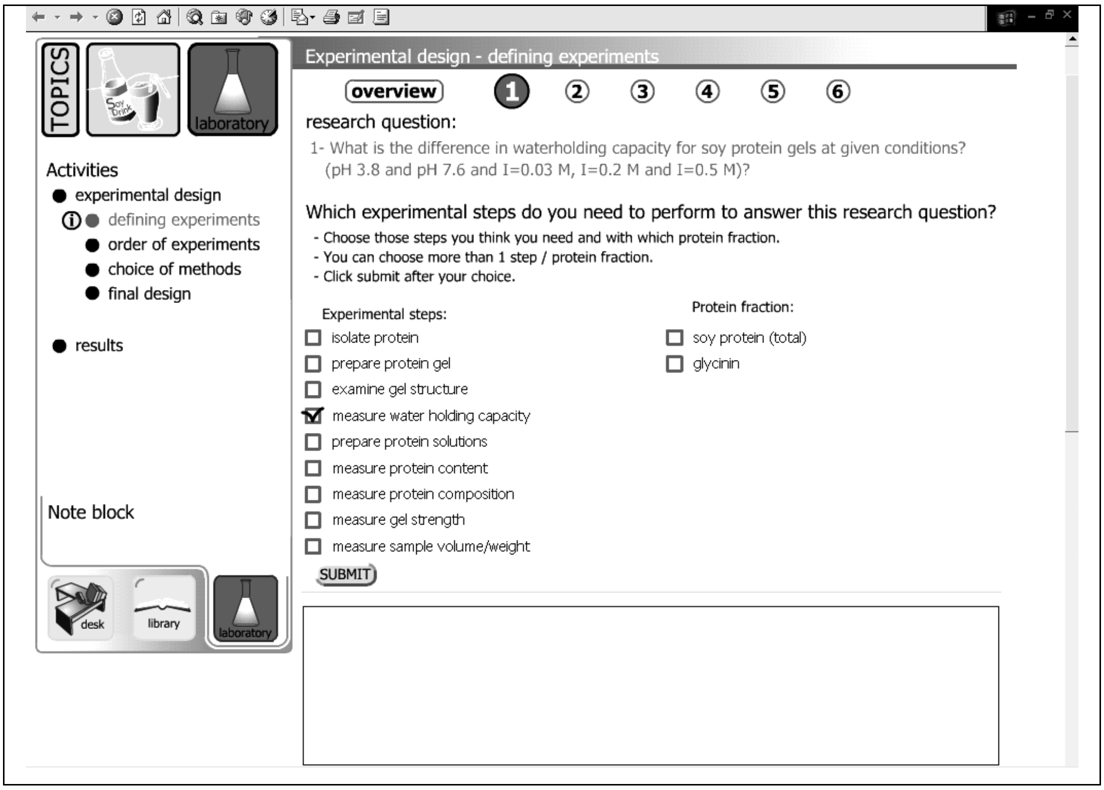

Figure 5.2A: Defining the experiments (phase A of the experimental design).

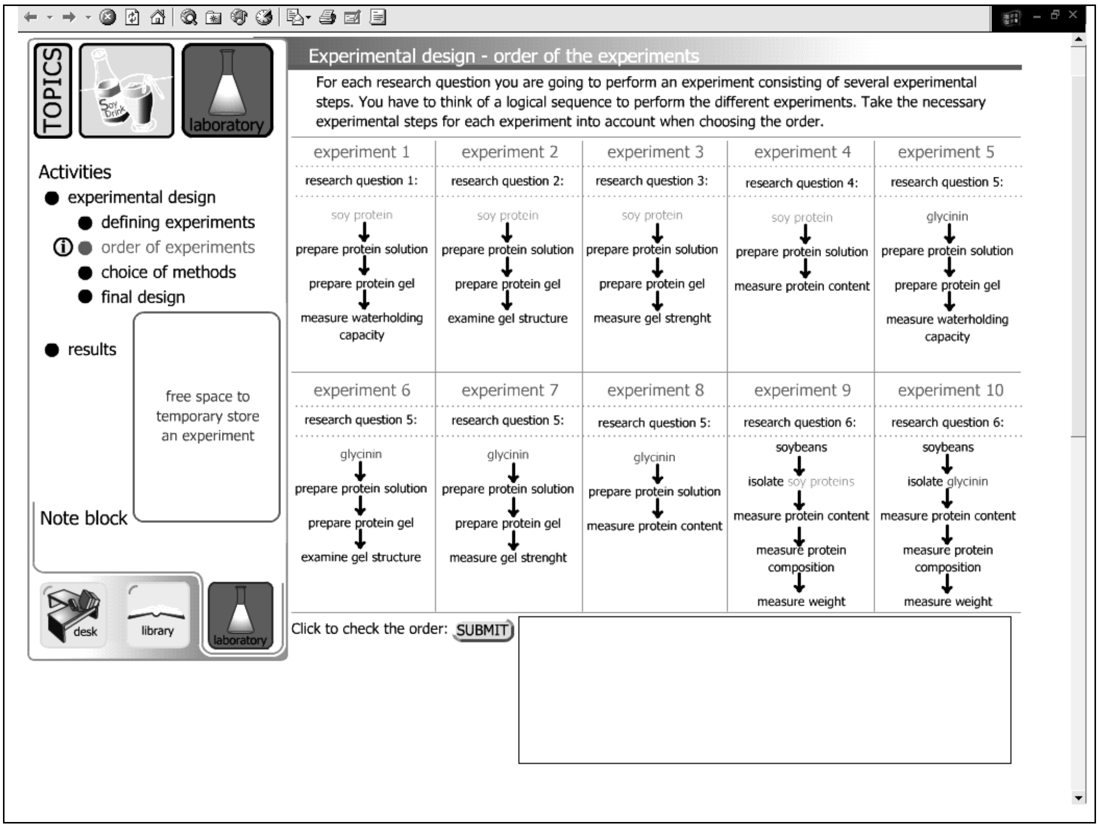

Figure 5.2B: Putting the experiments into a logical order (phase B of the experimental design)

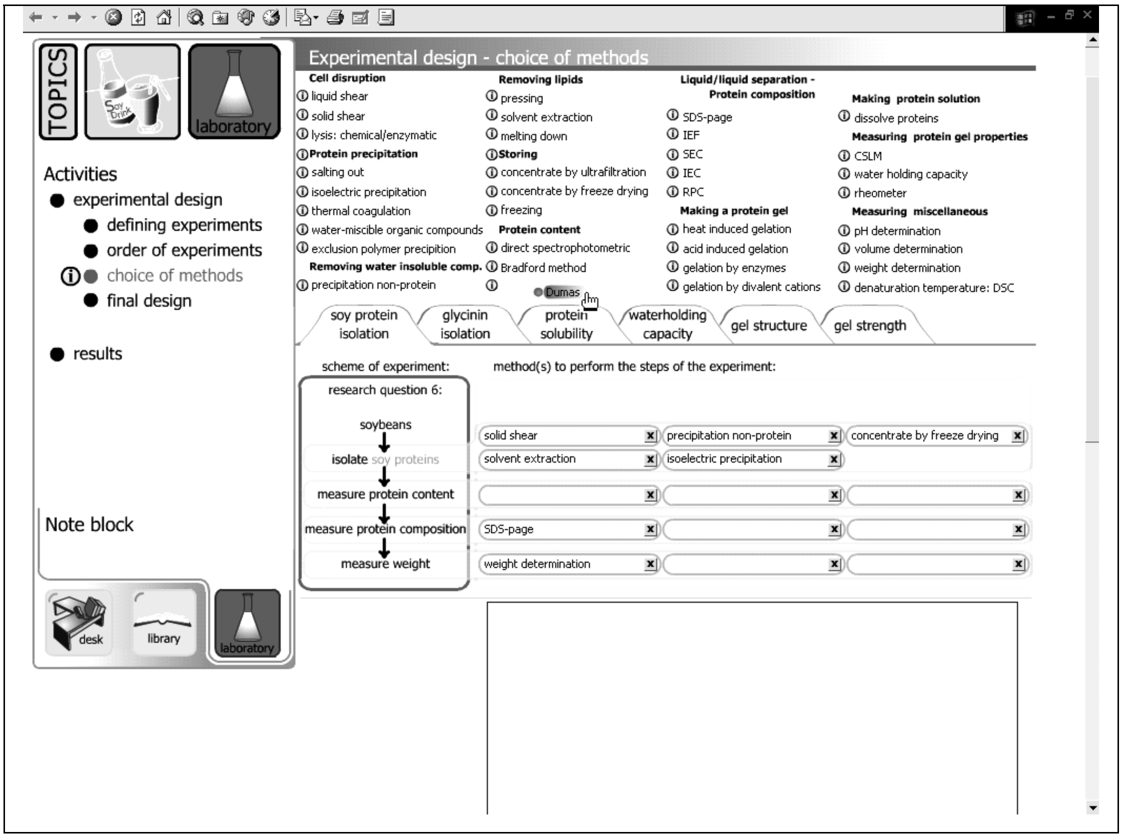

Figure 5.2C: Choosing of methods for the different steps in the experiments (phase C of the experimental design). At this moment the user is dragging the method 'Dumas' down.

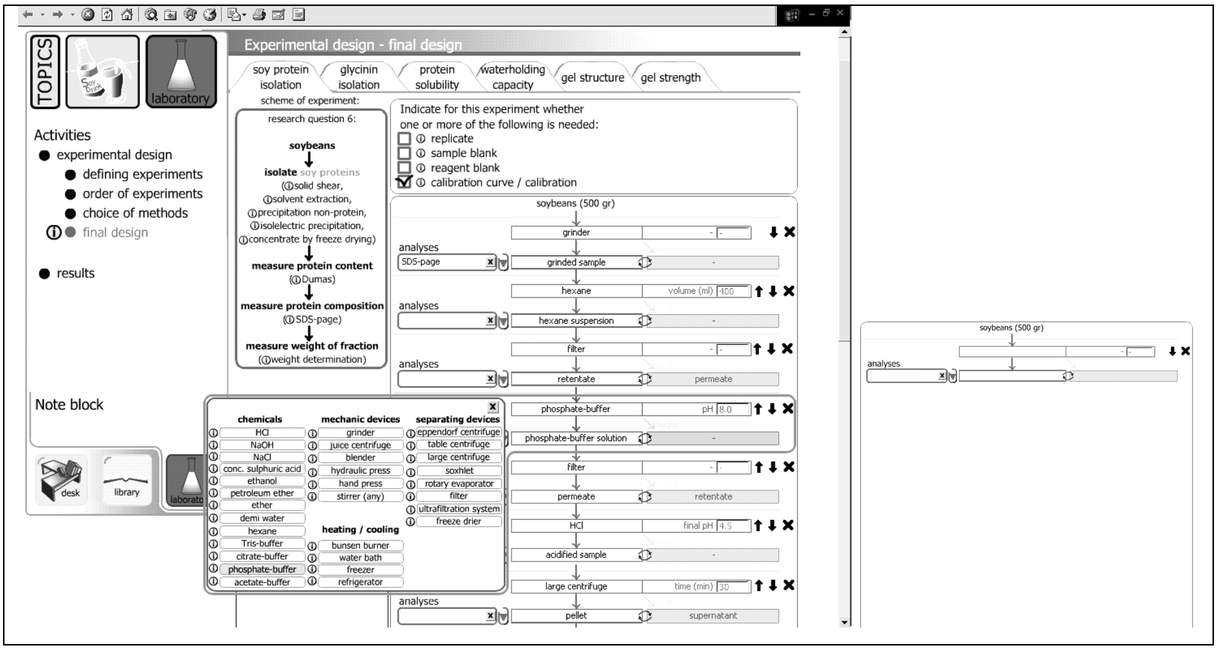

Figure 5.2D: The final design of the experiments (phase D of the experimental design). The large figure on the left shows an extended design. The small field on the right side shows that the field with all experimental procedures is first empty.

Phase D is the most complicated part of the design. Before explaining phase D, first an explanation of the general lay-out of an experiment is given with the help of Figure 5.3. 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.

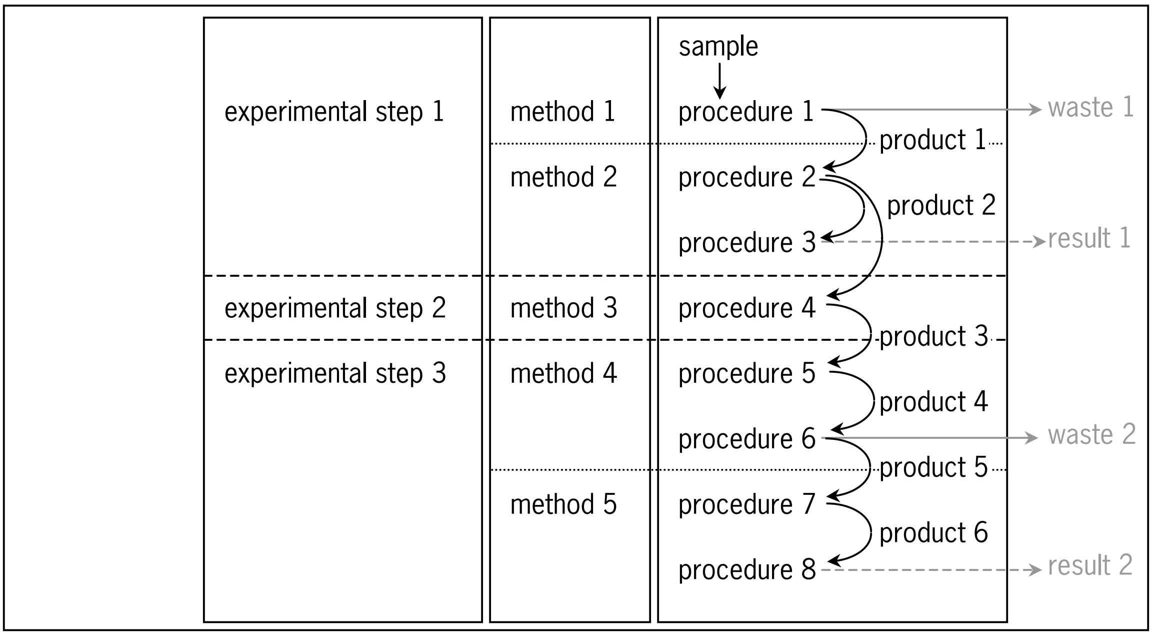

Figure 5.3: The general lay-out of a laboratory experiment.

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 by the curved and grey arrows in Figure 5.3), of which some are regarded as waste (represented by the solid grey arrows in Figure 5.3). 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 not a product, physically spoken, but is most often a qualitative or quantitative data point (represented by the dotted grey arrows in Figure 5.3). In the case of the skimmed milk, this milk could be analysed for protein concentration with a Nitrogen analyser, which results in 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 5.3) 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 5.2D, 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 5.2D). 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. in the case that the student has chosen to add a chemical to the sample, students are also requested 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 5.2D). An information button is enclosed for each method.
- Information buttons are added in front of the equipment, chemicals and analysis in the option menus for the procedures and analyses. When clicking on the information button a window is opened providing all necessary information.

- Students can submit their answers (also when the design is not finished, and they need guidance). 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 of the isolation of oil out of sunflower seeds, the percentage of protein soluble at a certain pH, or the α-tocopherol concentration. Just-in-time information is available in the form of a basic description on how to do 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
- keep the hypothesis, but need a new experiment to check it

Furthermore, students have to answer the research question 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 provided with a short list of pitfall examples and were asked to come up with at least 3 new pitfalls themselves, based on their experiences with laboratory classes. The pitfalls were added to the first list. 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. These pitfalls were marked by at least 30% of all respondents.

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. After correcting a mistake (a pitfall), students are provided with an explanation of the corresponding pitfall. 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. Then students can make one change and check this change or undo this change to make a different change. In this way, it is prevented that students can make more changes at once, with the risk that students change more than one pitfall before checking their changes. 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 8 weeks 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 hours): two for the first assignment, two for the second assignment and one for the third assignment. Before students attended the computer classes on a topic, they first got a few lectures on that topic. For example, students first followed the lectures on proteins before they worked on the assignment on soy-proteins. 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 hours) 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.

After these 6 weeks of lectures, computer classes and laboratory classes, students have one educational free week for self-study and one examination week, in which they take exams. The examination result of the course Advanced Food Chemistry constitutes 80% of the final grade. The grade for the laboratory classes constitutes 20% of the final grade. For the latter, a student is graded on his/her capabilities to plan and organise the experiments, their attitude towards their work and their fellow student, and the quality of the report and presentation.

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, nationality and Master specialisation 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, 63% hold the Dutch nationality, and 83% followed the Product Functionality specialisation of the Food Technology MSc (Master of Science) curriculum.

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 5.7 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 5.8) it can be said that students agreed they learned a lot from this course and the overall rating is satisfactory. From this, it can be said that students are in general satisfied with the learning activities in the course.

In the general course questionnaire, for the question 'Did the course require the time indicated in the prospectus, or less time or more time?' 12 students (38%) choose 'between 15% less and 15% more time', 14 students (44%) choose '15-30% more time' and 6 students (19%) choose '>30% more time'. From this it can be concluded that students perceive the course as rather intensive.

Quality of the computer classes

According to the answers of the general course questionnaire (Table 5.8), 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 5.8) 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 5.9 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.

Table 5.7: Learning effect and grading of different learning activities according to the students.

How much did you learn from ...	average* (n=24)	%4/5	%2
attending the lectures?	3.5	50	8
making the digital assignments?	3.6	54	8
doing the laboratory classes?	3.5	50	13
studying the book Food Chemistry?	3.9	62	0**

Rate each learning activity from 1 – 10.	rating# (n=23)	%7
lectures	7.1	78
digital assignments	7.3	70
laboratory classes	7.0	70

*: **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.

#: **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 5.8: 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 to 5, 1 = disagree, 5 = agree)
(%) is the percentage of students that agreed with the statements (% that answered 4 or 5)

Table 5.9: Quality of the assignments as perceived by students.

answer per assignment / item	first assignment (n=24)		second assignm. (n=24)		third assignm. (n=24)	
	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)

Clearly, students are not satisfied with the quality of the third assignment. Especially the high frustration for the third laboratory assignment (Table 5.9) is a worrisome aspect. During the interview with students it became clear that this frustration is high amongst others because some pitfalls were hard to detect and the hints were not specific enough to guide the students to the solution. Moreover, it was confusing to some students that, although the set-up of the third assignment looks equal to the first two assignments, students have to work with it differently.

Also according to the results of the general course questionnaire (Table 5.10) students are positive about the assignments with exception of the third assignment. It is remarkably that the first and the second assignments are equally graded for their value, while in the specific questionnaire students were clearly less positive about first assignment.

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 5.11 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 5.12, 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, 88% of all students scored more than or equal to 5.5 points and 73% 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.

Table 5.10: 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 to 5, 1 = disagree, 5 = agree)
(%) is the percentage of students that agreed with the statements (% that answered 4 or 5)

Table 5.11: 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)

Table 5.12: Results for the examination question related to the assignments.

question	maximum points	average* n=33	stand dev**
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 5.13: 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)

Relation between assignments and laboratory classes

For the relation between the assignments and laboratory classes the following questions need to be answered. Do students feel prepared for the laboratory classes? Do they use what they learned in the program in the laboratory classes? Did they remind the pitfalls from the third assignment when they were working in the laboratory classes?

According to Table 5.13 it can be concluded that 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 5.14 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 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'.

Table 5.14: 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)#
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)
#: This is the percentage of students that disagreed wit ht statement (% that answered 1 or 2)

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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Chapter 6 - General Discussion

INTRODUCTION

This thesis describes design oriented research that was aimed at the design and development of activating digital learning materials. From the forgoing chapters can be concluded that the activating learning materials improved the education in food chemistry. In each evaluation an appreciation of the students of the learning materials was noticed. Teachers can now easily provide any student, regular and non-regular, with activating learning materials. These learning materials are efficient for teachers, since 1) teachers can easily provide activating tasks to the students and 2) guidance of students during working on these tasks is largely taken over by the computer, which makes that 3) teachers have more time now to guide students with more specific needs and questions. These learning materials are efficient and motivating for students, since 1) the learning materials gives students the opportunity to work actively with the subject matter, 2) the support that students need during working on the tasks is to a large extent provided just-in-time by the computer, and 3) students can work on these materials whenever and wherever they prefer.

The three sets of learning material that were designed within this research are the *digital exercises* (to support students extensively in acquiring the required knowledge level), the *assignments on quantitative aspects* (to support students in acquiring quantitative problem solving skills in relation to the field of food chemistry), and the *assignments on research experiments* (to support students in learning how to design experiments: what options they have in analysing food and how to make choices between these options). Each of these learning materials were designed and developed with the help of design guidelines and aimed at satisfying preset design requirements. Both the guidelines and requirements were articulated specifically for these learning materials at the beginning of each design process. They were based on the viewpoints of three different fields: subject matter (food chemistry), education, and information and communication technology (ICT).

The sets of learning material serve as a proof of feasibility of successful development of digital activating learning materials using the design guidelines to satisfy the design requirements. Therefore, the design processes of these learning materials also serve as examples of *how* digital learning materials can be developed.

PROPERTIES OF THE DIGITAL LEARNING MATERIALS

The learning materials developed are all activating learning materials and students can use these learning materials individually. The learning materials share a number of properties: 1) the way interaction between the student and the computer is enabled, 2) the highly visual presentation of the learning materials, and 3) the use of various types of support within each learning material.

Interaction between student and computer

The research described in this thesis is based on the principle that in order to learn students need to perform an (mental or physical) activity. In this thesis information and communication technology (ICT) is used to induce this activity by students via activating learning materials. The several examples described in the former chapters give an idea of how ICT can be used to develop these activating learning materials. Students can interact with the computer by using the mouse and by using the keyboard. Interact means that the student acts on the computer and the computer acts on the action of the student. Two concepts have been used within the learning materials to enable students to act on the computer: 1) enable students to fill in a blank space with their answer and 2) enable students to make a choice or a set of coherent choices.

Fill in the blank concept

The fill in the blank concept has been used within the learning materials for two reasons: 1) to enable students to work on calculations, and 2) to enable students to come up with a textual input themselves, without giving options on the screen.

The fill in the blank concept allows the student to give almost any input, but the number of correct inputs is rather limited. For example, in the case of a calculation, the student is able to fill in any number, but only one specific number is regarded as the correct answer.

Within the assignments on quantitative problem solving skills (Chapter 4) the fill in the blank concept is used quite often. Students are asked to calculate a specific characteristic and to fill in their outcome in a text field. This input is an indication of what the student has achieved and depending on this input, specific feedback can be given. Within the assignments on research experiments (Chapter 5) the way students have to generate hypotheses is also an example of the fill in the blank concept. Here, the computer does not interpret the hypothesis that the student entered, so only non-specific feedback is returned.

The advantage of using random input is that the computer does not have to give away the answer to the students. So, students have to come up with a feasible answer themselves. In this way possible guessing behaviour is hindered. The disadvantages of using random input is that students can unintentionally make mistakes in typing in their correct answer. Also, it is difficult to control the answer, since computer-generated feedback is difficult to program on an input in words.

Make-a-choice concept

Several ways have been used to enable students to make a choice, which can be divided into two groups: 1) choosing between several items and 2) choosing the order of the items (putting items into an order). The digital exercises (Chapter 2) are all based on this make-a-choice concept. Also, the actions in the assignments on research (Chapter 5) are mainly based on this concept.

The advantage of the make-a-choice concept is that adequate specific feedback can be linked to each alternative that is offered to the student. The disadvantage of this make-a-choice concept is that the options are visible to the students. As a consequence, students do not have to come up with a feasible answer themselves and guessing behaviour can occur.

Several solutions were used within the digital learning materials to overcome the above mentioned disadvantage. Within the exercises a score was incorporated. When students made an incorrect choice, students did not earn any points or received a negative score. Since about 45% of the students stated that the score prevented them from guessing (Chapter 3), we propose that depicting a score on the computer screen is one way to prevent guessing. A second way that was used to prevent guessing within the learning materials, especially within the assignments on research experiments, was providing a large number of options and not mentioning to the students how many options need to be chosen and in which order. Guessing then becomes a time-consuming and useless activity.

Variation within the two concepts

Although only two concepts were used to activate the students, a large variation in tasks can still be provided to the students by means of a large variation in the presentation of the tasks. An example of two different tasks that use the same manner of activity, while a very different way of presentation has been used, is shown in Figure 6.1. In both cases the student has to move items from one place on the screen to a different place on the screen. The first screenshot shows a picture of a task in which the student has to move the items of the grey boxes on the right to the coloured spots on the left. The second screenshot shows a task in which the student has to move the items placed on the screen to change the order of the items. In the first task, students are completing three reaction equations and, therefore, besides choosing an order students also have to choose which items belongs to which reaction equation. In the second task students are putting experiments into a logical order.

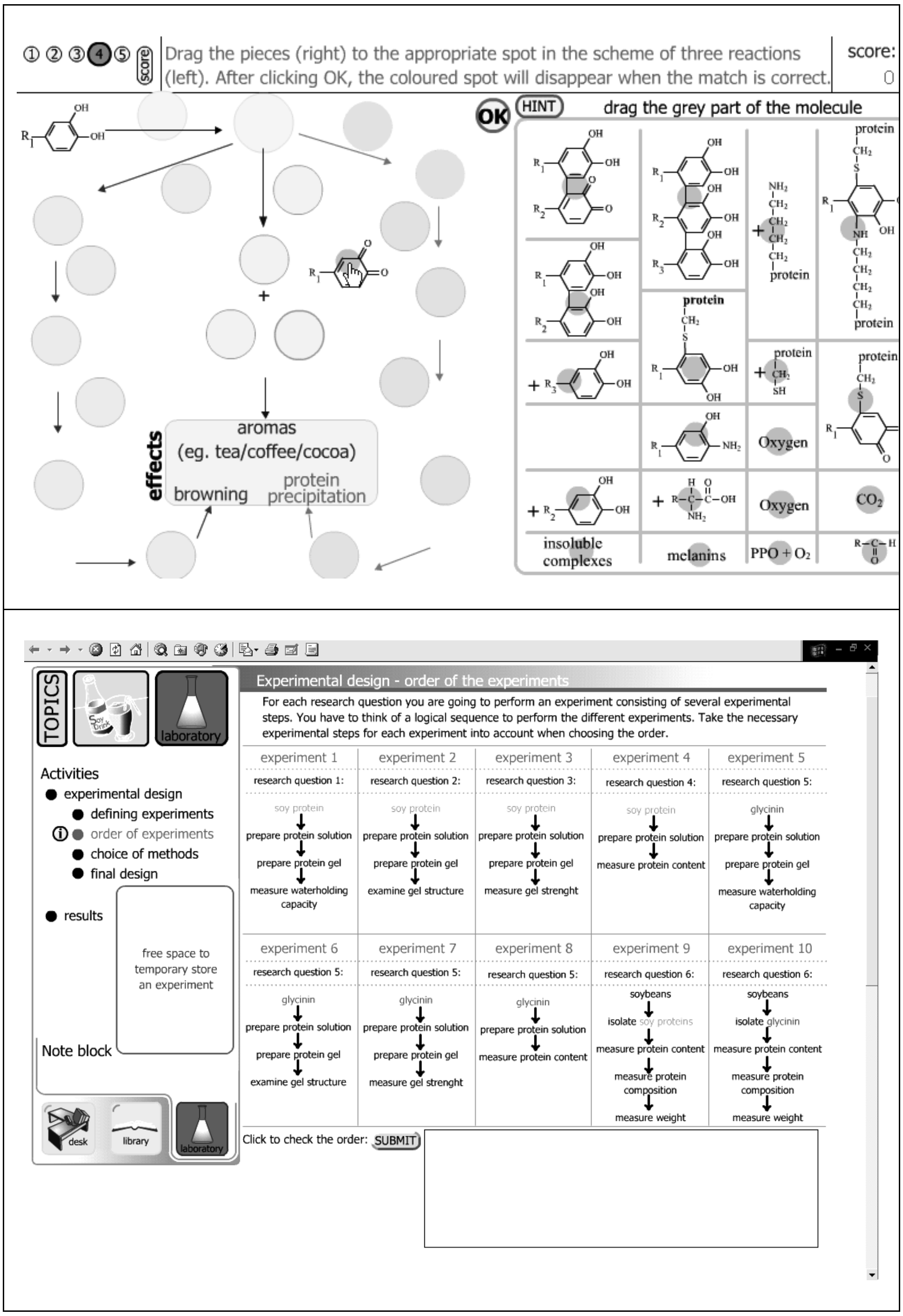

Figure 6.1: Two screenshots showing the same way to enable interaction between the student and the computer, but with a very different presentation.

The variation between the two examples is mainly the difference in the kind of visuals used. In the first screenshot, students work with molecular structures and at schematic reaction pathways. In the second screenshot, students work with schemas of experiments depicted by words and arrows. The second variation is the way the items are placed on the screen. In the first screenshot, the items that students have to move are placed at a different place than the target spots. In the second screenshot, the items are already placed at the target spots, but not at the correct spot.

Visual presentation of the learning material

The learning materials developed are heavily visually orientated. Visual presentation is accomplished by using for example pictures, figures, schemas, animations, colour, and a visual layout or structure. Visual presentation is known to be effective for learning (e.g. Mayer and Moreno, 2002). The visual presentations are used in several ways in the learning materials: several pictures and a highly visual structure.

First, many facts and concepts within the subject matter of food chemistry are explained in the digital learning materials by the use of pictures and other visual presentations. The field food chemistry (Belitz *et al.*, 2004; Fennema, 1996) consists of many 'visual' facts and concepts: the structure of a protein, the way charge influences the properties of a pectin molecule, the way lipids arrange in a crystalline structure, the way different enzymes can degrade starch, etc.

Second, the information in the learning materials described in this thesis is organised into highly *visual* structures. An example is depicted in Figure 6.2. This figure shows two screenshots of a part of the library of one of the assignments on research (Chapter 5). They contain information about the denaturation of proteins. The texts placed within this learning object nearly not include complete sentences. At the top there is a small animation (with the start button), which shows schematically what happens if a protein denatures. The effect of denaturation on the properties of a protein is made visible with five graphs (left screenshot). When clicking on one of the graphs a more extended description of this changed property is given, with some schematic pictures of the protein explaining the concept (right screenshot). Besides the information presented to the students, also several tasks that students need to perform are highly visual. In Figure 6.1 an example is given.

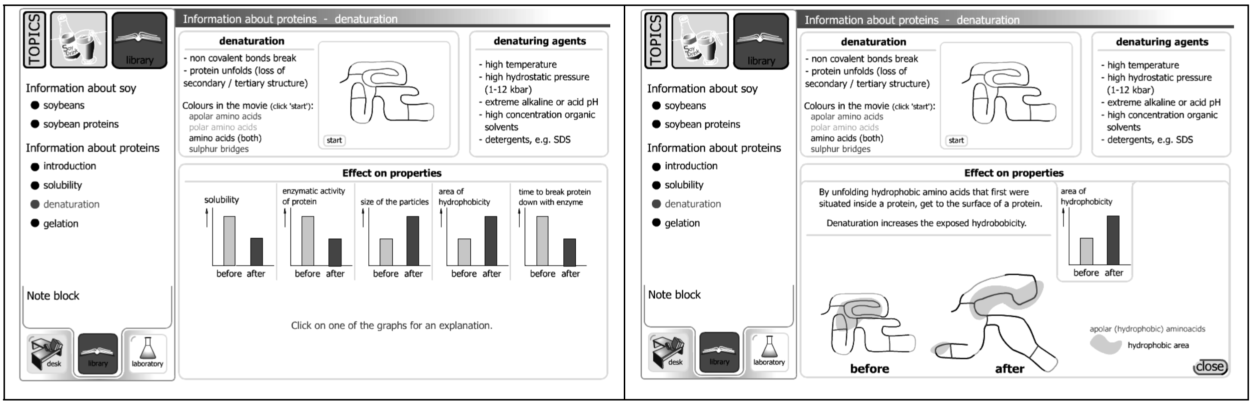

Figure 6.2: An example of how information is presented visually to the students within the digital learning material.

The assignments on quantitative aspects, the first set of learning materials designed within this research project, are much less visually orientated than the other learning materials. Throughout the design and development of the several learning materials the use of visualisation to present the subject matter and the tasks, became more and more applied. Therefore, the assignments on quantitative aspects are subject to improvement, including a more visual presentation and organisation of these assignments.

New foundation on visual presentation

In the evaluations of the learning materials with students, little attention has been paid to the aspect of visual presentation. Despite this, several remarks were placed by students that the learning materials 'look good' and that the visual presentations are regarded as 'helpful' and a 'welcome alternation' compared to the much less visualized textbooks or readers. From this, it is hypothesized that 'the digital learning material should explicitly aim at a visual presentation of information and the tasks' is a good additional educational principle for the design and development of activating digital learning materials within food chemistry. This also implies that more design guidelines regarding user interface design in relation to education should be employed within the learning materials than the few guidelines that were applied so far. For example, guidelines based on principles on how people learn from visuals or principles on how to make choices between different options in presentation.

Use of support

In the introduction of this thesis three types of support were defined: (explanatory and corrective) feedback, hints, and access to information. It turned out that a correct use of these types of support is essential for the success of the learning materials (Collis *et al.*, 2001; Moreno and Mayer, 2005). Table 6.1 gives an overview of the occasions in which the different types of support are used within the learning materials. Table 6.1 also indicates the importance of the different types of support for the different learning materials.

The results of the evaluation of the *assignments on quantitative aspects* (Chapter 4) show that the success of these assignments mainly relies on the hints that students receive that guide students step-by-step through a possible way to execute the sub-tasks. Also, access to specific information by providing hyperlinks at the moment that this information could be helpful to the student was regarded as an important factor. At last, students received corrective feedback on the answer of fill in the blank questions and a combination of corrective and explanatory feedback on the answer of multiple choice questions.

Table 6.1: Occasions when the different types of support are used within the learning materials

support	assignments on quantitative aspects	exercises	assignments on research
corrective feedback	+/- on each answer	++ on each answer	+/- on each answer
explanatory feedback	+ • when the answer is correct • on an incorrect answer to a multiple-choice question	+ • when the answer is correct • often on an incorrect answer to an exercise holding a large number of options	++ • often when the answer is correct • often on an incorrect answer to a task holding a large number of options
hint(s)	++ • on an incorrect answer to a fill-in-the-blank question • students can ask for a hint for a fill-in-the-blank question	+ • often on an incorrect answer to an exercise holding a large number of options • sometimes when the number of options is large students can ask for a hint	++ • on an incorrect answer to a random input calculation question • always on an incorrect answer to a task holding a large number of options
access to information	+ hyperlinks to information that could be helpful in that specific task	+/- hyperlink access to textual documents containing general information about the content of the exercise	++ hyperlinks are provided to information concerning the content of • the options within a task holding a large number of options • textual random input tasks

++: very important for success, +: important, +/-: helpful, but not success determining

Within the *digital exercises* (Chapter 2) all three types of support were used in several ways, although corrective feedback was the most important one to support students. Corrective feedback was often enough, especially for exercises with only a few options, to tell students which choice was correct and which one not. In this way, they can think of a different choice themselves. Corrective feedback within the exercises was often visual, e.g. a red cross for an incorrect or a green curl for a correct answer. For exercises with a large number of options (e.g. more than six) applying explanatory feedback and sometimes hints next to corrective feedback was noticed to be essential, since just trying every option is a useless and frustrating activity. Later on, to each exercise a hyperlink to a pdf-document containing information about the content of that exercise was added (not described in Chapters 2 and 3). From the evaluation at Cornell University and also an (not published) evaluation with users in the food industry, it became clear that several users prefer a hyperlink to additional, textual information. Also, some 'regular' students of the course Food Chemistry at Wageningen University indicated that they used these pdf-texts, although this information is a curtailed version of the texts already available to the students via the readers.

Within the assignments on research the need for support is high: For most tasks in these assignments, the number of options that students can choose from to perform the task is large. Making a considered choice requires sufficient information to make that choice. Since students have to make several choices from a large number of options, they explicitly need and are provided with access to quite some information. Moreover, because of this large number of options, hints and/or explanatory feedback are essential needs to be able to perform the tasks. This is for the same reason as for the digital exercises: when the number of options is high, guessing becomes useless and frustrating. The feedback and hints that students receive upon an incorrect answer, both show students why their thoughts were incorrect (feedback) and in which direction they should proceed (hint). It was noticed that when the feedback and hints were not proper or clear, some students got stuck, their frustration increased and their motivation dropped.

DESIGN GUIDELINES

As stated before, the design and development of the different learning materials were based on several design guidelines. In the introduction of this thesis it was explained that these guidelines are based on several fields (education, food chemistry subject matter, ICT and also HCI). The guidelines were described throughout the design and development processes of the different learning materials. Related to these guidelines the following will be reviewed: 1) the origin of most guidelines, and 2) the extent of generality of these guidelines.

Most guidelines described and used during the design processes *originated* from educational principles and from user interface design. These guidelines bridge the gap between the educational theories and principles and the practice of developing learning materials within food chemistry higher education. Almost no guidelines were based on the subject matter and also the number of guidelines on ICT was low. One explanation is that it is not field of the subject matter that needs to guide the development of learning material, but it is the combination between subject matter and education that guides this development. This combination can be defined as the didactics of the subject matter (also called 'pedagogical content knowledge') (Figure 6.3). The same counts for ICT: how users interact and can learn from a computer (which is called educational technology, Figure 6.3) is more interesting for the design of learning materials than then the possibilities of ICT in general. ICT should not guide the developer, but educational technology should guide the developer.

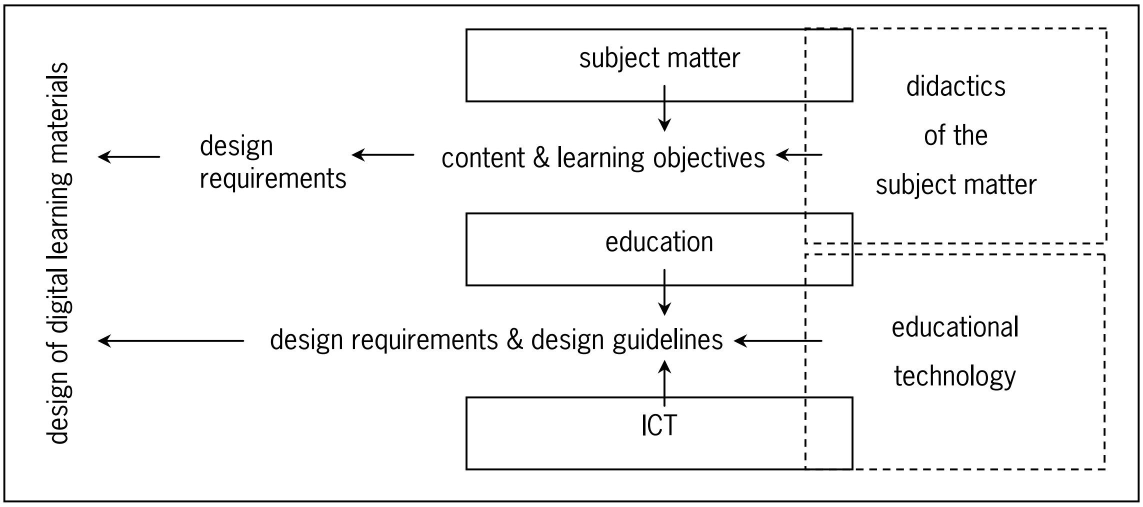

Figure 6.3: Relation between the fields of the subject matter, education and ICT with the design of digital learning materials, and the relationships between subject matter and education (the didactics of the subject matter) and between education and ICT (educational technology).

The guidelines described for the design of the assignments on quantitative aspects (Table 4.2, Chapter 4) were also used during the design of the exercises (Table 2.1, Chapter 2). The guidelines were sometimes rewritten and they were extended for the design of the exercises.

Moreover, although not mentioned in Chapter 5, most guidelines for the design of the exercises were also used for the design of the assignments on research experiments. Therefore, it can be said that these guidelines are quite generic and could be useful for learning materials with several learning objectives.

Besides the generic guidelines of the exercises, specific guidelines were described for the design of the assignments on research experiments (Table 5.2, Chapter 5). These guidelines are less generic, since these guidelines are more specific to the intended learning objectives of these assignments. From this it can be argued that guidelines need to be more specific when the learning materials itself also have more specific learning objectives. The assignments on research experiments have quite specific learning objectives (designing experiments, generating hypotheses, etc.), while the exercises have more general objectives, providing students with the possibility to practice with the subject matter to acquire knowledge of the very diverse subject matter. From this, it can be concluded that the design of the assignments on quantitative aspects also needs specific design guidelines, since these assignments also have more specific learning objectives.

In conclusion, it can be stated that the way interaction between the students and the computer can be varied, the specific use of the various types of support, and the highly visual presentation are regarded as the most important properties of the digital activating learning materials described in this thesis. To design activating digital learning material, the use of both generic and specific guidelines was noticed to be an important property of the design process.

Furthermore, it can be concluded that the digital activating learning materials improved the education in food chemistry. In each evaluation a positive appreciation of the students of the learning materials was noticed. Teachers can now easily provide any student, regular and non-regular, with activating learning materials.

The digital learning materials serve as a proof of feasibility of the design oriented research. Therefore, the design processes of these learning materials also serve as examples of how digital learning materials can be developed.

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Summary

In order to learn, people need to be active. Therefore, in education one has to find ways to activate students in a meaningful sense. A way to activate students is by providing them activating digital learning materials. The research described in this thesis is a design oriented research that aims at designing and developing activating digital learning materials for food chemistry education. It is expected that digital activating learning materials will provide an efficient and motivating situation for both teachers and students.

The learning materials described in this thesis were designed and developed with the help of design guidelines and aimed at satisfying preset design requirements. Both the guidelines and requirements were articulated specifically for these learning materials during the design processes. They were based on the viewpoints of three different fields: subject matter (food chemistry), education, and information and communication technology (ICT). In Chapter 1 these three fields are introduced. Various definitions and an overview of the field of food chemistry is given. Food chemistry is dealing with food systems, which are heterogeneous in its components, its possible reactions and its properties. Furthermore, three characteristics of food chemistry education are placed central in this thesis: the heterogeneity and the amount of the knowledge students need to construct, the choices between options to design experiments that students need to learn, and the quantitative problem solving skills that students need to acquire.

Chapter 1 also describes the courses Food Chemistry and Advanced Food Chemistry in detail. These are the courses for which the learning materials are designed, developed and evaluated. An overview of educational principles for the design of activating learning materials is given. The principles were 1) the learning material should contain motivating elements, 2) the learning material should prevent cognitive overload and 3) the learning material should contain supporting elements. Furthermore, the possibilities of the use of ICT within education are highlighted. This introductory chapter is concluded with an approach on the design and evaluation of activating digital learning materials. On basis of this approach the following digital activating learning materials are designed, developed and subsequently implemented and evaluated in food chemistry courses:

- *The exercises* : to support students extensively in acquiring the required knowledge level.
- *The assignments on quantitative aspects* : to support students in acquiring quantitative problem solving skills in relation to the field of food chemistry
- *The assignments on research experiments* : to support students in learning how to design experiments: what options they have in analysing food and how to make choices between these options.

The design of the *digital exercises* is described in Chapter 2. Design requirements and design guidelines are abstracted from the above mentioned three fields and it is explained how these guidelines are used to design the digital exercises. Also, formative evaluations with teachers, students, and experts in (food) chemistry/education/user-interface design were applied to test the digital exercises against the preset design requirements. An extensive description of the digital exercises is given, with several examples.

The evaluation of these exercises is presented in Chapter 3. The digital exercises are evaluated within three different case studies, each in the normal educational setting (during regular courses in food chemistry). The course structure and course organisation of each case study is specified. From the three case studies it was concluded that most design requirements, which were described at the start of the design process, were met. The evaluation results show that students' appreciation of the same learning material is different when applied in a different course structure and/or organisation. Furthermore, students experienced the exercises as clear and helpful. Most students confirmed that these exercises helped them in their preparations for the examination.

Chapter 4 describes the design and evaluation of *digital assignments on quantitative aspects*. Prior to the introduction of these assignments in the course, the learning activity that was used for the learning objectives of these assignments was inefficient for both students and teachers. The digital assignments have the intention to overcome this inefficiency. Most design guidelines that were used during the design are the same guidelines as used in chapter 2. The main characteristics of the assignments on quantitative aspects are that they guide students with just-in-time information and that they are divided into subtasks. The assignments were evaluated in three case studies in the normal educational setting. The results show that with these assignments frustration is low. Also, the time in classes is efficiently used, making it an efficient activity for both teachers and students.

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 these skills can be achieved more effectively with digital assignments than with laboratory classes. Therefore, three *digital assignments on research experiments* are designed and developed, which is described in Chapter 5. These assignments have, amongst others, the following two goals: 1) providing a situation in which students can practice research specific cognitive skills, which are hard to train in laboratory classes, and 2) offering a research method, which students can also use in a real laboratory situation. The assignments are described in detail. Results of a first evaluation of the use of the assignments indicate that the students find the assignments challenging and valuable. Although students indicate to have learned a useful research method, it was observed that students do not apply the method in the laboratory classes.

In Chapter 6 specific properties of the digital learning materials and the design guidelines described during the design processes of the different learning materials are reviewed. The way interaction between the students and the computer can be varied, the specific use of the various types of support, and the highly visual presentation are regarded as the three most important properties of the digital activating learning materials described in this thesis. Furthermore, to design activating digital learning material, the use of both generic and specific guidelines was noticed to be an important property of the design process.

It can be concluded that the digital activating learning materials improved the education in food chemistry. In each evaluation a positive appreciation of the students of the learning materials was noticed. Teachers can now easily provide any student, regular and non-regular, with activating learning materials. The digital learning materials serve as a proof of feasibility of the design oriented research. Therefore, the design processes of these learning materials also serve as examples of *how* digital learning materials can be developed.

Samenvatting

Om te leren, moeten mensen actief zijn. Om deze reden wordt in onderwijs naar manieren gezocht waarmee studenten betekenisvol geactiveerd kunnen worden. Een manier waarmee studenten geactiveerd kunnen worden, is door activerende leermaterialen te verschaffen. Het onderzoek dat in dit proefschrift beschreven wordt, is een ontwerponderzoek dat het ontwerpen en ontwikkelen van activerende digitale leermaterialen beoogt. Er wordt verwacht dat het gebruik van digitale activerende leermaterialen een situatie kan voortbrengen die voor zowel docenten als studenten efficiënt en motiverend is.

De leermaterialen beschreven in dit proefschrift zijn ontworpen en ontwikkeld met behulp van ontwerprichtlijnen, waarbij het behalen van van tevoren vastgestelde ontwerpeisen beoogd wordt. Zowel de richtlijnen als de eisen zijn specifiek voor deze leermaterialen opgesteld tijdens het ontwerpproces. Ze zijn gebaseerd op de standpunten van drie verschillende velden: onderwerp (levensmiddelenchemie), onderwijs en informatie en communicatie technologie (ICT). In Hoofdstuk 1 worden deze drie velden geïntroduceerd. Verscheidene definities en een overzicht van het veld van de levensmiddelenchemie worden gegeven. Levensmiddelenchemie behandelt systemen welke heterogeen zijn in zijn componenten, zijn mogelijke chemische reacties en zijn eigenschappen. Verder zijn drie karakteristieken van het onderwijs van de levensmiddelenchemie centraal geplaatst in dit proefschrift: de hoeveelheid en heterogeniteit van de kennis die studenten moeten construeren, het leren maken van keuzes tussen opties bij het ontwerpen van experimenten en de vaardigheden welke studenten moeten verwerven voor het kwantitatief oplossen van problemen.

Hoofdstuk 1 beschrijft de vakken Food Chemistry en Advanced Food Chemistry in detail. Deze zijn de vakken waar de leermaterialen voor ontworpen, ontwikkeld en geëvalueerd zijn. Een overzicht van de onderwijskundige principes voor het ontwerpen van activerende leermaterialen is gegeven. De principes zijn 1) het leermateriaal dient motiverende elementen te bevatten, 2) het leermateriaal dient een te veel aan cognitieve lading (cognitive overload) te verhinderen en 3) het leermateriaal dient ondersteunende elementen te bevatten. Daarnaast worden de mogelijkheden van het gebruik van ICT in onderwijs aangestipt. Dit introductiehoofdstuk wordt afgesloten me een aanpak voor het ontwerpen en evalueren van digitale activerende leermaterialen. Op basis van deze aanpak zijn de volgende digitale activerende leermaterialen ontworpen, ontwikkeld en vervolgens geïmplementeerd en geëvalueerd in levensmiddelenchemische vakken:

- *De exercises* : ter ondersteuning van studenten voor het verwerven van de gewenste kennis.
- *De assignments on quantitative aspects* : ter ondersteuning van studenten voor het verwerven van vaardigheden voor het oplossen van kwantitatieve problemen in relatie tot de levensmiddelenchemie
- *De assignments on research experiments* : ter ondersteuning van studenten bij het leren hoe een experiment te ontwerpen: welke opties er zijn in het analyseren van levensmiddelen en hoe een keuze te kunnen maken tussen deze opties.

Het ontwerp van de *exercises* is beschreven in Hoofdstuk 2. Ontwerprichtlijnen en ontwerpeisen zijn gebaseerd op de eerder genoemde drie velden. Een uitleg wordt gegeven over hoe de ontwerprichtlijnen zijn gebruikt voor het ontwerp van de exercises. Formatieve evaluaties met docenten, studenten en experts in (levensmiddelen) chemie/onderwijs/gebruikersinterface-ontwerp zijn uitgevoerd ter controle van de exercises tegen de ontwerpeisen. Een uitgebreide beschrijving van de exercises wordt gegeven, met verschillende voorbeelden.

De evaluatie van deze exercises wordt beschreven in Hoofdstuk 3. De exercises zijn geëvalueerd in drie verschillende case studies, elk in de normale onderwijssetting (tijdens de reguliere levensmiddelenchemische vakken). De structuur en organisatie van het vak is voor elke case studie gespecificeerd. De resultaten van de case studies bevestigen dat aan de meeste ontwerpeisen, welke aan het begin van het ontwerpproces opgesteld waren, voldaan is. Daarnaast laten de resultaten zien dat de waardering van de studenten voor hetzelfde leermateriaal verschillend is bij een verschillende structuur en/of organisatie van het vak. De studenten ervoeren de exercises als duidelijk en nuttig. De meeste studenten bevestigden dat deze exercises hen hielpen bij de voorbereidingen op het tentamen.

Hoofdstuk 4 beschrijft het ontwerp en de evaluatie van de *digital assignments on quantitative aspects*. Voorafgaand aan de introductie van deze assignments in het vak was er een andere leeractiviteit voor de leerdoelen van de assignments. Deze leeractiviteit was inefficiënt voor zowel docenten als studenten. De digitale assignments hebben tot doel om deze inefficiënte situatie te verbeteren. De meeste ontwerprichtlijnen die gebruikt zijn tijdens het ontwerpen van de assignments waren dezelfde richtlijnen als gebruikt in Hoofdstuk 2. De belangrijkste eigenschappen van de assignments on quantitative aspects zijn dat ze studenten begeleiden met behulp van just-in-time informatie en dat ze zijn opgedeeld in subtaken. De assignments zijn geëvalueerd in drie case studies in de normale onderwijssetting. De resultaten laten zien dat de frustratie van de studenten laag is tijdens het werken aan deze assignments. Tevens wordt de tijd efficiënt gebruikt, waardoor het een efficiënte activiteit is voor zowel docenten als studenten.

Laboratoriumpractica zijn vaak inefficiënte leeractiviteiten voor studenten en ondersteunen studenten vaak ontoereikend bij het ontwikkelen van onderzoek gerelateerde cognitieve vaardigheden. Het is verondersteld dat een aantal van deze vaardigheden efficiënter verworven kunnen worden met digitale opdrachten dan met een laboratoriumpracticum. Om deze reden zijn drie digitale *assignments on research experiments* ontworpen en ontwikkeld, wat beschreven is in Hoofdstuk 5. Deze assignments hebben onder andere de volgende twee doelen: 1) een situatie bieden waarin studenten onderzoek gerelateerde cognitieve vaardigheden, welke moeilijk te trainen zijn met laboratoriumpractica, kunnen oefenen, en 2) een onderzoeksmethode bieden, welke studenten ook kunnen gebruiken in een echte onderzoekssituatie. De assignments worden in detail beschreven. De resultaten van een eerste evaluatie van het gebruik van de assignments geven een indicatie dat de studenten de assignments uitdagend en nuttig vinden. Hoewel studenten aangeven dat ze een nuttige onderzoeksmethode geleerd hebben, werd opgemerkt dat studenten deze methode niet gebruiken tijdens het laboratoriumpractica.

In Hoofdstuk 6 worden specifieke eigenschappen van de leermaterialen en van de ontwerprichtlijnen, die beschreven zijn tijdens de ontwerpprocessen van de verschillende leermaterialen, besproken. De manier waarop de interactie tussen de studenten en de computer gevarieerd kan worden, het gebruik van de diverse manieren van ondersteuning en de zeer visuele presentatie worden gezien als de meest belangrijke eigenschappen van de leermaterialen beschreven in dit proefschrift. Daarnaast is het gebruik van zowel generieke als specifieke ontwerprichtlijnen gezien als een belangrijke eigenschap van het ontwerpproces van leermaterialen.

Geconcludeerd kan worden dat het gebruik van de activerende leermaterialen het onderwijs in levensmiddelenchemie verbeterd heeft. Elke evaluatie heeft een positieve waardering van de studenten voor het leermateriaal laten zien. Docenten kunnen nu vrij eenvoudig elke student, regulier en niet regulier, voorzien van activerende leermaterialen. De leermaterialen fungeren als een bewijs van realiseerbaarheid van ontwerpgericht onderzoek. Derhalve fungeren de ontwerpprocessen van deze leermaterialen als voorbeelden van *hoe* digitale activerende leermaterialen ontwikkeld kunnen worden.

Dankwoord

Werken aan een natuurwetenschappelijk onderzoek, experimenteren in een lab, voor vier jaar? Nee, dat is niks voor mij. Al snel na mijn afstudeervak wist ik dat ik geen AIO zou willen worden. Toch hoefde ik eigenlijk niet eens heel lang na te denken toen Harry naar mij toe kwam om te vragen of ik misschien zou willen promoveren op het ontwerpen van digitaal leermateriaal. Ik was op dat moment serieus de stap aan het overwegen richting de lerarenopleiding. De combinatie levensmiddelenchemie en onderwijs was daarom erg interessant. Dat het om digitaal leermateriaal ging, maakte het alleen maar nog interessanter. Dat ‘e-learning’ erg belangrijk zou gaan worden in onderwijs, daar waren al velen van overtuigd. Dus ik zag genoeg toekomstperspectief in deze baan.

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Bas, naast 'collega' ben je natuurlijk ook mijn beste vriendje. Ik hoop dat we samen nog heel veel zullen mee maken, dat al onze dromen mogen uitkomen, want jij bent 6 op de schaal van 1 tot 5!

Curriculum Vitae

Julia Diederen is geboren op 27 augustus 1977 te Tilburg. In 1995 behaalde zij haar VWO diploma (Atheneum) aan het Bernardinus College te Heerlen. In datzelfde jaar begon zij aan de opleiding Levensmiddelentechnologie aan de toenmalige Landbouw Universiteit te Wageningen. Zij volgde de specialisatie Levensmiddelenchemie welke werd afgesloten met een afstudeervak bij de leerstoelgroep Levensmiddelenchemie. Zij liep een stage aan de University of Arkansas bij de Food Science Group (Arkansas, USA) en een tweede stage bij Douwe Egberts, SaraLee (Utrecht). Haar tweede en tevens afsluitende afstudeervak heeft zij gedaan bij de leerstoelgroep Levensmiddelennatuurkunde. Zij studeerde af in september 2000 aan de Wageningen Universiteit. Per oktober 2000 was zij als promovenda in dienst van Wageningen Universiteit bij de leerstoelgroep Levensmiddelenchemie. Haar promotie ontwerponderzoek was een onderdeel van het FBT2-programma van de Wageningen Universiteit, dat het ontwikkelen van digitale leermaterialen als centrale doelstelling heeft. De resultaten van dit promotie ontwerponderzoek staan beschreven in dit proefschrift. Momenteel, sinds november 2004, is zij werkzaam bij de leerstoelgroep Levensmiddelenchemie als medewerker onderwijsontwikkeling.

COURSES, CONFERENCES AND SEMINARS

- Ed-media conference (2002, Denver USA and 2004, Lugano Zwitserland)
- ICT in higher education conference (2002)
- ESERA onderwijs conferentie (2003)
- KNCV conference (2003)
- Conference 'Zin en onzin van ICT in hoger onderwijs' (Open Universiteit, 2004)
- Flash seminars (2000, 2003)
- SURF seminars (2000, 2000, 2004)
- Course 'Flash master class' (Promate, 2001)
- Course 'PGO Tutoren training' (Wageningen Universiteit, 2001)
- Course 'Afstudeervak organiseren en begeleiden' (Wageningen Universiteit, 2004)
- Course 'Basiscursus didactiek' (Wageningen Universiteit, 2004 - 2005)
- Course 'Scientific writing' (Wageningen Universiteit, 2001 - 2002)
- Food Chemistry PhD study trips (2002, USA and 2004, Japan)

List of Publications

Diederen, J., Gruppen, H., Voragen, A.G.J., Hartog, R., Mulder, M., Biemans, H. (2002). Design guidelines for digital learning material for food chemistry education. *Ed-Media 2002 World Conference on educational multimedia, hypermedia & telecommunications*, Denver, CO, USA

Aken, G.A. van, Zoet, F.D., Diederen, J. (2002). Composition of thin films between emulation droplets stabilized by protein, as measured in highly concentrated emulsions. *Colloids and Surfaces B: Biointerfaces*, 26:269-279

Diederen, J., Gruppen, H., Hartog, R., Moerland, G., Voragen, A.G.J. (2003). Design of activating digital learning material for food chemistry education. *Chemistry Education: Research and Practice*, (4)3:

Diederen, J., Gruppen, H., Hartog, R., Voragen, A.G.J. (2005). Evaluation of computer-based learning material for food chemistry education. *Chemistry Education: Research and Practice*, 6 (2): 64-82

Diederen, J., Gruppen, H., Hartog, R., Voragen, A.G.J. (accepted for publication). Design and Evaluation of Digital Learning Material to Support Acquisition of Quantitative Problem Solving Skills within Food Chemistry Education. *Journal of Science Education and Technology*

Diederen, J., Gruppen, H., Hartog, R., Voragen, A.G.J. (submitted). Design and Evaluation of Digital Assignments on Research Experiments within Food Chemistry.