DESIGN AND EVALUATION OF DIGITAL LEARNING MATERIAL FOR ACADEMIC EDUCATION IN HUMAN NUTRITION

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ABSTRACT

This thesis addresses the design, development and evaluation of interactive activating digital learning materials for academic Human Nutrition Education. It focuses on how principles derived from educational theories guided the design of these learning materials. Therefore guidelines based on evidence derived from theories on learning and instruction and information technology were identified and further articulated for Human Nutrition Education. These guidelines aim to motivate the students to become actively involved in studying and to avoid unnecessary load of students' cognitive capacity.

Digital learning materials were developed to assist students to

- understand the concept of confounding and to account for it in data analysis.
- understand and use the theory of planned behaviour within a nutrition behavioural research context.
- formulate meaningful research questions and experiments in the field of nutrigenomics.
- match basic statistical analysis methods with study types in Human Nutrition research and conduct the analysis.
- evaluate the strengths and limitations of common approaches in Human Nutrition research.

All learning materials were evaluated against preset criteria within academic educational settings. In general, students and teaching staff appreciated the materials, and most students achieved the learning objectives.

During the design, development and evaluation of the learning materials knowledge was developed and experience was gained on the formulation of learning objectives, on frequently occurring misconceptions by students, on the use of adequate representations and examples, on educational activities which appeared useful to activate the student, on the selection of relevant design guidelines and on design patterns which can be reused for the design of learning materials. This knowledge can be characterized as Pedagogical Content Knowledge (PCK), i.e. specific and articulated knowledge on problems, core issues and the application of general educational theories in teaching Human Nutrition. The design process revealed the need to develop PCK and at the same time provided the means to develop it. Moreover, this PCK appeared relevant to guide the actions and decisions of academic teaching staff and of developers of learning materials.

CONTENTS

CHAPTER 1

General introduction

Scope

Human Nutrition is a multidisciplinary scientific domain. This means that insights from several life sciences (e.g. biochemistry, physiology, molecular biology) and social sciences (e.g. sociology and psychology) need to be mastered, to understand the role of dietary and life style factors in human health and disease. Consequently, the main challenge in academic Human Nutrition Education is to cover learning objectives that aim at obtaining knowledge from the above described scientific disciplines, and at the same time to offer opportunities to develop in-depth knowledge and research skills related to the core content of Human Nutrition.

In advance, it was assumed that the use of digital learning materials could offer several educational and practical benefits to approach this challenge. For example, it was assumed that animations and visuals could be used to assist students in understanding important methodological research principles and concepts, that interactive exercises and activities could be used to activate each student individually, that feedback could be tailored to the need of an individual student, etcetera. To explore whether the use of interactive digital learning materials could indeed be valuable for Human Nutrition Education, this thesis describes the design, development and evaluation of digital learning materials according to principles of so-called design oriented research. Therefore, this introduction first elaborates on the core contents and the main educational challenges of Human Nutrition Education. Second, five educational principles which played a key role during the design of the digital learning materials are described, and a short introduction to the aims and methodology of design oriented research is presented.

The domain of Human Nutrition

To characterize the core content of Human Nutrition, six textbooks (published after the year 2000) are reviewed (1-6). Only textbooks which aim to cover the broadness of Human Nutrition are included, leaving out textbooks that cover specific sub domains of Human Nutrition (for example (7, 8)). Since the selection of textbooks is arbitrary, this paragraph does not pretend to give a systematic review of all published textbooks. Instead it aims to give an overview of definitions of Human Nutrition used in these textbooks and an impression of the topics which are covered.

Definitions

The definitions of Human Nutrition in these six textbooks emphasize the biological aspects of Human Nutrition. For example Human Nutrition is defined as 'the science of foods and the nutrients and other substances they contain, and their actions within the body (including ingestion, digestion, absorption, transport, metabolism, and excretion)' (1) or as 'the science that describes the processes whereby cellular organelles, cells, tissues, organs, systems and the body as a whole obtain and use necessary substances obtained from foods to maintain structural and functional integrity' (2). On the other hand, broader definitions include the social, economical, cultural, and psychological implications of food and eating. For example Mann *et al* describe Human Nutrition as 'the science that deals with all effects on people of any components found in food' (3). In addition to the reviewed textbooks, also other publications emphasize the integrative and multidisciplinary nature of Human Nutrition, for example by defining nutrition science as 'the study of food systems, foods and drinks, their nutrients and other constituents, and their interactions within and between all relevant biological, social and environmental systems.' (9) or by describing nutrition as a reservoir of integrative science (10, 11) or by drawing attention to the role of social research in the integrated science of nutrition (12).

Core content

Despite its multidisciplinary nature, Human Nutrition has its own unique core content. Allen *et al* (11) describe this core content as knowledge on structure and metabolic functions of nutrients and other dietary constituents, knowledge on food, diets and supplements, knowledge on nutritional status assessment, knowledge on nutrition and disease, knowledge on nutrition interventions and policies and knowledge and skills related to research methodology. To get a better view on the core content of Human Nutrition, Box 1 provides an overview of the content of the reviewed textbooks.

Box 1: core content of Human Nutrition textbooks#.

Body composition and macronutrient metabolism
Body size and composition
Physiology of nutrient digestion and absorption
Energy metabolism
Carbohydrates
Lipids
Proteins
Alcohol

Function of micronutrients, organic and inorganic nutrients
Water, electrolytes and acid-base balance
Minerals and trace elements
Water-soluble vitamins
Fat-soluble vitamins

Clinical nutrition
Overweight and obesity
Cardiovascular diseases
Cancers
Diabetes mellitus
Osteoporosis
Eating disorders
Deficiency disease

Foods
Food groups
Food patterns
Food safety
Functional foods
Supplements and nutraceuticals

Dietary requirements
Dietary reference standards
Nutritional recommendations
Pregnancy and lactation
Infancy, childhood and adolescence
Nutrition and ageing
Sport nutrition
Nutritional deficiency

Research methodology
Nutritional assessment methods
Food composition tables
(Nutritional) Epidemiology
Intervention studies

Nutrition policy
Food supply
Hunger
Poverty

Reviewed textbooks: Gibney, Foster and Kok (2002), Mann and Truswell (2002), Eastwood (2003), Whitney and Rolfes (2004), Geissler and Powers (2005), Wildman and Medeiros (2007) (1-6). Topics covered by less than three of the reviewed textbooks are not mentioned.

After an introduction to Human Nutrition and food composition, most textbooks start with a section about macronutrient (carbohydrates, lipids, protein) metabolism. Often this section includes a chapter about body composition and sometimes a section on energy metabolism. The next section of most textbooks deals with micronutrient function (vitamins, minerals and trace elements) and functions of other organic and inorganic constituents (such as water, electrolytes and other bioactive components in plant food). Depending on the aim of the textbooks sections are included on nutritional assessment methods, life stage nutrition, public health nutrition, nutrition policy etc. Most recent textbooks often include sections related to nutrigenomics research and system biological approaches (4). While these approaches are becoming more and more important in Human Nutrition research, it can be expected that most textbooks will cover them in future editions.

Research domains

Besides textbooks covering the core content of Human Nutrition, more research-oriented text and handbooks cover the research methodology, see for example (13-16). With respect to research methodology, several publications distinguish three or even more conceptual levels or levels of organizational complexity on which biological aspects of nutrition can be studied, although the description of the levels and their boundaries are somewhat different (2, 11, 17):

1. Nutritional genomics and genetics at the cell, tissue or organ level.
2. Nutritional physiology and clinical nutrition at the individual level.
3. Nutritional epidemiology and public health nutrition at the level of the population and the society.

The above mentioned textbooks mainly focus on the biological aspects of nutrition, however some of them also cover social and behavioural aspects, for example in a section on food policy or public health. Social and behavioural aspects can be seen as an integral part of the science of nutrition (12, 18). Research on these aspects focuses on the individual level as well as on the level of the population and society.

Academic Human Nutrition Education

Because of the multidisciplinary nature of Human Nutrition, the main challenge in academic education is to find the proper balance between focusing on basic understanding of life and social sciences, and focusing on in-depth and specialized knowledge and research skills related to the core content of Human Nutrition. An additional challenge is that Human Nutrition education often has to deal with heterogeneous student groups with respect to prior knowledge, interests and future career choices.

Curricula

Worldwide, a broad range of curricula include the domain of Human Nutrition. At the one end are full curricula in 'Human Nutrition' (e.g. the curricula in Human Nutrition of Cornell University or Wageningen University). These curricula offer a solid understanding of the biological, social and behavioural aspects of Human Nutrition together with a strong training in research methodology. Besides covering the full disciplinary spectrum of Human Nutrition, these curricula offer opportunities to develop expertise in one or more sub domains of Human Nutrition. At the other end are the universities which offer nutrition courses as part of curricula in biological or health sciences (for example Human Nutrition courses as part of the Health Science curriculum at the University of Maastricht). In general, students enrolled in these curricula first obtain general education in the life sciences. Human Nutrition courses or specializations are offered as part of these curricula. In general, these courses focus on sub domains of Human Nutrition (e.g. molecular nutrition, public health nutrition, nutritional epidemiology etc), depending on the research focus of the department or the university. Consequently the primary objective of these courses is not to obtain insight into the full disciplinary spectrum of Human Nutrition.

The balance between covering the broadness of Human Nutrition and offering an in-depth specialized training depends on the aims of a curriculum. If it aims to train students as fundamental scientific researchers in e.g. nutrigenomics or nutritional epidemiology, an in-depth methodological and research oriented training is more important than a broad training in all aspects, including the social aspects, of Human Nutrition. On the other hand, if the aim is to train all-round nutritionist who can function within both a scientific and a governmental or industrial context, a broad training that covers all aspects of Human Nutrition is required.

It is beyond the scope of this introduction to provide an in-depth discussion of the differences and similarities between Human Nutrition curricula. Instead, the next paragraph describes the curriculum of Wageningen University as an example. Because the learning material described in this thesis is evaluated within this curriculum, knowledge on this curriculum is helpful to understand the evaluation of the learning material described in the chapters 2 to 6.

Human Nutrition Education in Wageningen

The Human Nutrition curriculum "Nutrition and Health" at Wageningen University focuses on the role of diet and life style factors in human health and disease. Box 2 gives a detailed overview of the competences and Appendix 1 of the courses in this curriculum. Students enrolled in the Bachelor programme attend courses which aim at obtaining knowledge and understanding of the core content and broadness of Human Nutrition. In addition they attend courses which aim at obtaining knowledge from scientific disciplines related to Human Nutrition and courses aiming at acquiring general academic attitudes and skills. Within the three-year Bachelor programme each student has to select one out of three course clusters as an orientation on the specialisation in their Master programme.

After the Bachelor programme, most students continue with a 2-year master programme in Nutrition and Health. Next to these students, students with bachelor degrees related to Human Nutrition (e.g. a vocational training in dietetics, a BSc degree in Nutrition obtained elsewhere, a BSc in Food Sciences, Medical Sciences, Biomedical Sciences etc.) are also eligible for this Master programme when they meet specific conditions to programme content and grades. As a result, especially the student group enrolled in the master programme is heterogeneous with respect to prior knowledge. The Master programme offers the opportunity to develop expertise in one or more sub domains of Human Nutrition as well as a strong methodological oriented training by means of attending courses, participating in at least one master thesis project and an internship.

Educational principles

To assist students in achieving the competences described in Box 2, several educational activities can be used. Usually a curriculum consist of courses in which the student participates in several educational activities, like following lectures, doing laboratory assignments, studying textbooks, participating in working groups, attending tutorial sessions, studying digital learning material etc. Which educational activity is most appropriate for a given situation depends, among others, on the learning objectives, students prior knowledge, available resources (like time, computers, laboratories etc), student characteristics, teachers preferences etc. It falls outside the scope of this thesis to compare different educational activities. Instead, this paragraph explains why using digital learning material could be a valuable strategy to assist students in studying Human Nutrition.

Box 2: Competences of the Nutrition and Health curriculum (Wageningen University)

BSc **1st & 2nd year**	**Compulsory courses to meet the core competencies:** Students should be able to understand and apply principles from life and social sciences within a Human Nutrition context, they should develop research skills related to all sub domains of Human Nutrition, and general academic attitudes and skills.	
BSc **3rd year**	**Course cluster: Mechanisms of Nutrition and Health** Students should develop knowledge on food safety, nutritional metabolism and the mechanisms at the organ, cell or sub cellular level.	**Additional courses** to broaden or deepen knowledge
	Course cluster: Human Nutrition and Health Students should develop knowledge on the biomedical, analytical approach toward Human Nutrition, studied at the population or individual level.	
	Course cluster: Lifestyle in Nutrition and Health Students should develop knowledge on social and behavioural aspects of nutrition and the methods to influence behaviour.	**BSc-essay**
MSc **1st year**	**Compulsory and optional courses to meet the core competence:** Students should be aware of the possibilities and limitations of the various approaches in Human Nutrition research and be able to critically evaluate and communicate their intricate interrelationships as well as their unique possibilities and limitations.	
	Specialization: Nutrition in Health and Disease Students should be able to identify nutritional requirements for optimal health of individuals or groups and to conduct dietary intervention studies.	**Specialization: Food toxicology** Students should develop knowledge on the effects of hazardous substances in the diet and should be able to translate the toxicological evidence to practical guidelines for safe foods.
	Specialization: Public Health Nutrition Students should be able to identify health problems in populations, propose dietary and lifestyle solutions, and plan their implementation and evaluation.	**Specialization: Nutritional physiology** Students should master the principles of *in vitro* or *in vivo* experiments to elucidate physiological mechanisms involved in homeostatic control.
	Specialization: Nutritional and Public Health Epidemiology Student should be able to study dietary determinants of health and disease by participating in observational nutritional research or health promotion programs.	**Specialization: Molecular Nutrition** Students should master the principles of experiments in *in vitro* or *in vivo* model systems to elucidate molecular and cellular mechanisms underlying physiological effects of nutrients.
MSc **2nd year**	**Internship**	**Master thesis project**

BSc students attend courses to master the core competences. Next, they choose at least two courses from one of the course clusters, and broaden or deepen their knowledge by selecting additional courses. Furthermore, they write a bachelor essay. MSc students attend courses to meet the core competences and courses related to one of the six specialisations. Next they participate in a master thesis project and internship. Appendix 1 gives an extended overview of the courses within each cluster or specialization.

For the design of digital learning material several educational principles are considered useful. The five key principles relevant for this thesis are shortly summarized below. For each principle its relevance to the design of digital learning material is explained. The underlying philosophy, which leads to the selection of these key principles, is that learning takes place through active construction of knowledge. This process can be facilitated by providing learning material that stimulates the student to become actively involved in studying and which is designed to make effectively use of the students cognitive capacity.

Principle 1: Motivate the student

Motivation is essential for learning (19, 20). According to the ARCS model of Keller (21), four factors are essential to motivate the students: Instruction should capture the Attention of the student, it should be perceived as Relevant, and it should induce Confidence and Satisfaction. Research on motivation shows that when people expect to do well, they tend to try hard, they persist and perform better. Furthermore it shows that students who believe to have personal control on their own learning and behaviour are more likely to do well and that high levels of interest (intrinsic motivation) are associated with more engagement, more learning and higher levels of achievement (22). Based on these findings, several principles are provided which could be used to design motivating education. Examples of these principles are, providing tasks that are within the range of competence for students, providing clear and accurate feedback, providing material and tasks that are personally meaningful and interesting to the students, including novelty and variety in tasks and activities etc. Digital learning material provides sufficient opportunities to implement these principles and to motivate the student. This will become clear from the description of the next four educational principles. However, it is important to search the added value of digital learning material not solely in the possibilities to increase students' motivation. Also other educational approaches could provide sufficient possibilities to motivate the student (for example an enthusiastic lecturer, the participation in research projects etc).

Principle 2: Authentic learning context

Active construction of knowledge can be supported by providing meaningful, realistic and authentic learning contexts which reflect the way knowledge is used in "real life" (23-25). Because one of the general learning objectives in the domain of Human Nutrition is that students become able to understand and apply principles derived from related scientific disciplines (like biology, biochemistry, sociology, psychology etc), it is important to provide a meaningful Human Nutrition related context. Digital learning material provides ample opportunities to provide an authentic learning context. For example, digital learning material can be used to provide a simulated virtual laboratory environment in which the student can freely design and try out experiments (26, 27). Or within digital learning material the student can be put in an authentic role of a scientific researcher (see chapter 4) or a consultant of a consultancy firm (28) and so on. Using these role simulations provide a safe learning environment in which the student can explore situations he could encounter in his further career. Other examples of authentic learning contexts' are the use of real life data sets in learning material aiming at the development of data analytical skills (see chapter 5) or the use of authentic, actual, yet unresolved research questions, as topic of learning material aiming at obtaining insight into strengths and limitations of nutritional research approaches (see chapter 6). Although these examples clearly illustrate the added value of digital learning material, they do not claim that digital learning material can fully replace educational activities like the participation in research projects, laboratory classes etc.

Principle 3: Active learning

Active learning and practice is necessary for strengthen understanding, acquiring knowledge and retention of knowledge (29, 30). Especially digital learning material provides ample opportunities to engage each student individually in studying. With digital learning material a broad range of interactive exercises (like drag and drop questions, multiple choice questions etc) and other activities (e.g. interactive simulations, interactive practice possibilities for data analysis) can be provided that will stimulate the student to learn actively.

Principle 4: Visualization of important concepts

An important added value of digital learning material is the possibility to use dynamic visuals (e.g. interactive diagrams, animations and video clips) which are more elaborated than figures in textbooks (31, 32). Mayer claimed that: "the promise of multimedia learning is that students can learn more deeply from well-designed multimedia messages consisting of words and pictures than from more traditional modes of communication involving words alone" (33). Furthermore, it is suggested that well-designed images or diagrams can improve understanding and retention of knowledge (30, 34, 35). With respect to visualization, the challenge during the design of the digital learning material is to investigate which representations (such as animations, schemas, pictures etc) are adequate to clarify a certain rule, concept or principle.

Principle 5: Reduce unnecessary cognitive load

According to cognitive load theory, an individual's cognitive capacity is limited. There is a certain amount of information that a student can process at a certain time (30, 36, 37). This influences learning performance especially when the objective is to master complex cognitive skills. These are skills which are complex in the sense that they comprise a set of constituent skills of which the majority is in the cognitive domain and of which at least some involve conscious processing (38). Most of the learning material described in this thesis aims at achieving learning objectives that pertain to such complex cognitive skills. Therefore, cognitive overload is likely to occur frequently unless special measures are taken. Preventing cognitive overload is one of the major challenges, because of the multidisciplinary nature of the domain of Human nutrition.

Digital learning material provides several opportunities to prevent cognitive overload. One principle is the use of Just-In-Time (JIT) information presentation (39). This means providing the student with information and feedback at exactly the moment he needs this information to perform a task. Which information is needed by a student depends (among others) on his/her prior knowledge and skills. The JIT-information presentation principle is especially important when dealing with heterogeneous target groups. Other ways to prevent cognitive overload are providing part task practice and whole task practice separately and the adequate sequencing of information (38, 40). For part-task practice, the learning task is broken down into components which can be practiced separately. During whole task practice several of the part tasks are combined. Furthermore, ordering whole and part task practice according to the complexity of particular tasks can reduce cognitive load. Chapters 4 and 5 illustrate how digital learning material can promote part task practice in a whole task context, in order to prevent that the student will train each sub skill separately but will not become able to integrate the sub skills to perform the whole task.

Design Oriented Research

This thesis describes so-called design oriented research focusing on the design, development and evaluation of digital learning materials. Design oriented research aims at the production of new knowledge by means of designing a product. During this research, prototypes or realized designs (here digital learning materials) are designed and developed and design principles are articulated and applied. These prototypes or realized designs and the design principles can serve as an inspiration for the development of other learning materials and could support developers and designers in their tasks. Consequently, the ultimate goal of design oriented research is not the empirical investigation of the effectiveness of digital learning material compared to other learning materials or other educational strategies. Instead, it aims to obtain knowledge on the articulation of design principles and to illustrate how these principles facilitate the development of a product that satisfies certain requirements, as a 'proof of principle'. Research methodology of design oriented research is still discussed in literature (41-43). Figure 1 summarizes the most important aspects of the design oriented research process. Although depicted as a linear process, in fact a design oriented research process is a cyclic process in which analysis of the design challenge, the design of a blue print of the product, the development, formative evaluation and revision of the product are iterated (43).

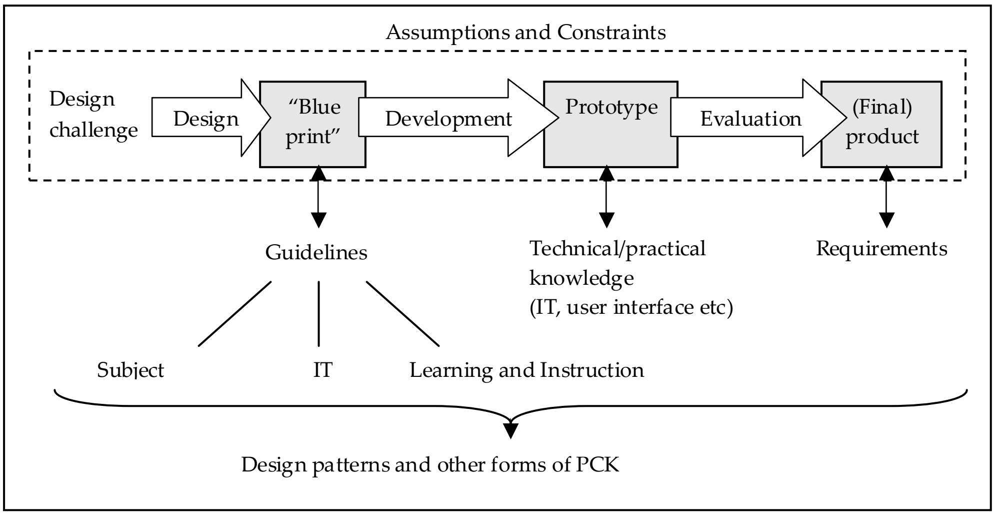

Figure 1: Design oriented research.
See the text for an extended explanation of the design oriented research process.

The design process

Several stimuli can initiate the development of digital learning material. For example, the assumed added value of digital learning material could initiate projects in which digital learning materials are developed. Often digital learning material is designed to approach existing educational problems or challenges. In addition, the desire to introduce new learning objectives, to develop new courses or to develop distance learning courses can reveal opportunities for the development of digital learning materials. These initial purposes of the learning material determine the scope of the design process which is reflected by the design assumptions.

An important aspect of the design of digital learning material is the identification of principles that could provide guidance to the design process. According to Weston *et al.* (44) design of digital learning material should follow guidelines from instructional design theories (e.g. the above-described educational principles), subject matter (learning objectives), language (semantic issues) and presentation (e.g. user interface design). During the design process appropriate guidelines are selected, further articulated and specified in relation to the content and learning objectives of the learning material.

Besides the identification of design guidelines, the design process consist of several other sub processes such as a learning task analysis, detailed formulation of the learning objectives, selection of topics for the learning material, design of interactive exercises, design of information presentation etc. This design process aims at the development of a 'blue print" of the learning material e.g. a storyboard which visualizes important properties of the learning material. Developing a 'blue print' instead of direct realization of the material brings along several advantages. For example revising a "blue print" is usually cheaper than revising materials. In addition some "blue prints" can emphasize properties of the learning material (for example, the underlying feedback structure for exercises or the underlying mathematical model for a simulation) which are not clearly visible once the design is realized. Furthermore, a storyboard facilitates communication between designers, developers, and subject matter experts.

The development process

The actual development of the learning material requires practical and technical knowledge on for example information technology and user interface design. At the same time, the development process generates new practical and technical knowledge. This can result in the development of so called design patterns. A design pattern is a recurrent pattern in configurations of components or basic operations that fits a certain type of problem or challenge. Such patterns emerge by using the articulated guidelines to design and develop practical solutions for the problems or challenges. The knowledge of an expert designer consists of many design patterns. The concept of design patterns was first introduced by Alexander (45). During the last decade, the concept has received more attention in education (46, 47). Examples of design patterns are specific types of interactive exercises, a principle of information presentation, a principle to give feedback during an interactive exercise etc. These design patterns can be reused to approach similar design challenges.

The evaluation process

Formative evaluation of the learning material aims at identifying shortcomings of the learning material in use. Requirements are formulated representing the demands that the final implemented material should meet. These requirements provide a further articulation of the design goals and are used to evaluate if the process of design, development and implementation of the digital learning material brought us to the goals. In the end, evaluation and subsequent revision of the learning material results in the final learning material. Because design requirements are formulated before and during the design process they also provide guidance to the design and development of the materials.

Design assumptions and constraints

Design assumptions define the scope of the design and development process. Design assumptions regarding the environment in which the learning material has to function reflect the initial purposes of the learning material. From a design-oriented perspective, the environment in which the digital learning material functions consists of the educational setting in which the material will be used, the students who use the learning material and the technical facilities that enable the use of the material. However, to design learning material that is suitable for use in different environments, the design of the learning material needs to be based on a set of assumptions about its environment that is minimal in terms of scope and impact. In addition to design assumptions, design constraints specify boundaries of the design process. Examples of such constraints are budgetary or technical constraints.

Outcomes of design oriented research

Due to the above described nature of a design oriented research process, the outcome of the research process is not restricted to (prototypes of) digital learning materials and its evaluation, but also includes Pedagogical Content Knowledge (PCK) development. PCK can be seen as specific and articulated knowledge on problems, core issues and the application of general educational theories in teaching a certain subject discipline (in this case Human Nutrition). The key elements of PCK are knowledge on strategies and representations useful for teaching a particular subject matter, and knowledge on students' understanding, conceptions and misconceptions of the subject matter (48, 49). A broader definition of PCK includes knowledge on subject matter per se, knowledge on media for instruction (50), general pedagogical knowledge and knowledge on the environmental context of learning (51, 52). To judge the value of a design oriented research process it is important to evaluate not only whether the realized and implemented learning material fulfils the design requirements once it is in use, but also includes an evaluation of the design process, the design guidelines and the PCK which arises.

Aim and outline of this thesis

This thesis describes the design, development and evaluation of digital learning material for several sub domains of Human Nutrition. More specifically:

- The design process aims at the identification and analysis of design challenges and the further articulation and explication of principles from theories on learning and instruction and information technology for several learning objectives in Human Nutrition Education.
- The development process aims at the development of prototypes of digital learning materials including reusable design patterns.

- The evaluation process aims to investigate if the implemented learning material fulfils the requirements. Furthermore, it aims to identify shortcomings of the learning material and to provide suggestions for improvement.

The learning materials were designed iteratively during consecutive design, development, evaluation and revision cycles. They were developed serially to benefit from previous obtained knowledge and experience. The development order was mainly determined by university timetables, to guarantee optimal timing of the evaluation within academic courses and to ensure serial development.

Chapters 2 to 6 describe the design and development of learning materials for several sub domains of Human Nutrition in the order of development. Each chapter gives a justification of the design process and illustrates how the above-described principles from theories on learning and instruction are applied. In addition, each chapter describes the evaluation of the learning materials within an academic educational setting. Table 1 gives an overview of the learning materials and design principles described in each chapter. Finally, chapter 7 discusses the main outcomes of the design oriented research process which includes a comparison of design principles used for the different materials, a discussion of the identified design patterns, the PCK which was developed and the evaluation methods.

Table 1: Overview of the learning material described in this thesis.

Ch	Content	Domain of Human Nutrition	Described design principles
2	Confounding	Nutritional epidemiology	General principles derived from theories on learning and instruction.
3	Theory of Planned Behaviour	Social nutritional research	General principles, detailed guidelines for JIT information presentation.
4	Nutrigenomics	Nutritional genomics and genetics	JIT presentation principles, detailed guidelines for interactive exercises.
5	Applied data analysis	Data analysis within nutritional epidemiology and clinical nutrition	Detailed guidelines for learning tasks analysis and part/whole task practice, design patterns.
6	Research methodology	Nutritional genomics and genetics, clinical nutrition, nutritional epidemiology	Description of design patterns

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CHAPTER 2

The role of active manipulation of three-dimensional scatter plots in understanding the concept of confounding

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Abstract

In teaching epidemiology, confounding is a difficult topic. The authors designed active learning objects (LO) based on manipulable three-dimensional (3D) plots to facilitate understanding of confounding. The 3D LOs illustrate how confounding can occur, how it generates bias and how to adjust for it.

For the development of the LOs, guidelines were formulated based on epidemiology and theories of instructional design. These included integrating the conceptual and empirical aspects: the causal relationships believed to be operating in the study population (conceptual aspect) and data-oriented associations (empirical aspect). Other guidelines based on theories of instructional design included: actively engage the students, use visual methods when possible, and motivate the students about the importance of the topic.

Students gave the method strong positive evaluations. Experts in epidemiology agreed that the 3D LOs apply generally accepted scientific views on confounding. Based on their experiences, the authors think that the 3D plots can be an useful addition in the teaching of confounding. The article includes links and a downloadable file that provide a demonstration of the 3D LO-based teaching materials.

[1]The appendix describes additional learning material to illustrate how 3D LOs were used to assist students in obtaining experience with the use of linear multivariate regression models to adjust for confounding during data analysis. This appendix was not included in the original paper.

Introduction

A major goal in teaching epidemiology is that students master the concept of confounding. They should understand when confounding may occur, how it can result in bias, and how to assess the presence of confounding and adjust for it.

As described by Rothman (1), "on the simplest level, confounding may be considered a confusion of effects. Specifically, the apparent effect of the exposure of interest is distorted because the effect of an extraneous factor is mistaken for or mixed with the actual exposure effect". (See Newman or Greenland for more fundamental definitions of confounding (2, 3)). A confounding factor therefore must be: (a) a risk factor of the disease (in the unexposed), based on biological and epidemiological evidence, which requires information not included in the data; and (b) imbalanced between the exposure groups, which depends on the study design and population. In a dataset, these two criteria imply that a confounding factor must be associated with the disease and exposure. The third criterion for confounding is based on the causal relations between exposure, disease and confounding factor; this also requires information not included in the data. Rothman describes this third criterion as follows: (c) "A confounding factor must not be affected by the exposure or disease. In particular, it cannot be an intermediate step in the causal pathway between the exposure and the disease" (1).

Despite theoretical and practical work in our courses, problems in understanding confounding become clear when, in one of our courses, students analyze a dataset of a cross-sectional study. To do this, first the biological background of the exposure-outcome relation and potential confounding factors are presented. Next the students evaluate confounding using three plots: (a) of the crude association between exposure and outcome, (b) of the association between the potential confounding factor and the outcome and (c) of the association between the potential confounding factor and the exposure. Based on this information, the student must conclude whether confounding is present in the data and whether the crude association seen in the first plot provides a valid representation of the causal relationship between exposure and outcome in which the student is interested.

Communication with students indicated that knowledge of the criteria and their application to the dataset is not sufficient for understanding confounding. For example, it appeared difficult to imagine that confounding can invert the apparent direction of the effect of exposure. Several explanations of the unsatisfactory level of understanding can be put forward. One explanation is that students have to study the joint (three-dimensional) distribution of the exposure, outcome and confounding factor, but they have to use three separate (two-dimensional) plots instead of one three-dimensional plot. Obviously, simultaneously conceptualizing the three graphs requires complex cognitive processing and this could lead to cognitive overload. Another possible explanation is that most epidemiological textbooks tend to distinguish two aspects of confounding: In all textbooks, there is emphasis on a priori (prior to data collection) criteria for confounding (conceptual aspect) and on the evaluation of confounding by comparing crude and adjusted estimates (empirical aspect). The conceptual aspect focuses on background knowledge about the causal network that links exposure, outcome and potential confounders, which corresponds to the classical definition of confounding. The empirical aspect focuses on statistical associations within the data and corresponds to the collapsibility definition of confounding (2, 3). For students it seems difficult to understand how these two aspects are related.

To facilitate understanding of confounding, we developed digital learning objects (LOs) based on three-dimensional (3D) scatter plots. In the following, we describe the guidelines and requirements for the design of the 3D LOs, describe the 3D LOs and provide a hands-on example for the reader, and evaluate the results.

Analysis

Design process

Three-dimensional learning objects were designed for two courses: a BSc course (6 ECTS: European Credit Transfer System) which gives an introduction on study designs and the biases and an MSc course (6 ECTS), which focuses on data-analysis.

To direct the design process, guidelines were formulated, based on theories of instructional design (learning and teaching) and subject matter (content issues and learning goals). Students, teachers, and experts in epidemiology evaluated whether the requirements were fulfilled. In the next section, the guidelines and requirements that played a major role in the design of the 3D LOs are described. Emphasis is put on guidelines based on subject matter. Table 1 summarizes the guidelines, the requirements and the evaluators.

Table 1: Description of guidelines and requirements.

Guidelines.	Requirements for the 3D LOs	Evaluation by
Based on subject matter and learning goals		
Use rotatable 3D plots.	Students and experts perceive the 3D LOs as a valuable addition to the textbook.	Students and experts
Integrate the conceptual and empirical aspect of confounding.	Teachers confirm that the 3D LOs support the learning goals for confounding.	Experts
	Experts in epidemiology confirm that the 3D LOs apply accepted scientific views on confounding.	
	Experts in epidemiology confirm that it is useful to use the 3D LOs in addition to epidemiological textbooks and lectures.	
	80% of the students are able to answer exam questions (which integrate the conceptual and empirical approach) correctly.	Evaluation of exams
Based on learning and instruction theories		
Actively engage the students (4).	Students feel that the elements in the 3D LOs that require them to become active learners help them to understand confounding.	Students
Visualize important concepts. (5, 6).	Students perceive the plots in the 3D LOs as a valuable addition to the textbook.	Students
	Students feel that actively manipulating the 3D plots helps them to understand confounding.	
Motivate the students (based on ARCS model (7)): the LOs should:	Students feel that the elements that require them to become active learners motivate them to study.	Students
- capture the Attention of the student,	Students judge the material with at least a 4 (on a five-point scale).	
- be received as Relevant	Students feel they learned from the 3D LOs.	
- induce Confidence and Satisfaction by students.	The student is able to solve the exercises.	

Design guidelines based on subject matter

Guideline: Use rotatable 3D plots

Providing an appropriate 3D illustration of the underlying 3D relationship, to help students to understand the concept of confounding, was the primary goal of this effort. Because epidemiological analyses usually deal with higher dimensional datasets, higher dimensional visualization techniques are used to design the 3D plots. These techniques aim at viewing several variables in the same representation, using computer-supported, interactive, visual representations of abstract data, to amplify cognition (4). Several statistical software packages (such as SAS/insight and SPSS) offer three-dimensional visualization tools, like 3D scatter plots.

Some authors have recommended 3D scatter plots as tool for understanding statistical concepts (5) and as a tool for analyzing data (6, 7). Fox *et al*. stated that 3D scatter plots could be potentially useful when two-dimensional plots fail to reveal structure in the data, e.g. in case of certain kinds of clustering and non-linearity (8). In addition, Yu found that subjects performed better in detecting outliers and examination of non-linear relationship using 3D plots than using 2D plots (9). However, in these studies non-linear functions were used, so the conclusions should not be over-generalized to linear functions. In general, the use of a 3D plot instead of three 2D plots is helpful because a relationship between three variables may not be visible in 2D plots. A 3D plot, which can be rotated by the student, provides a better view of the distribution of the three variables in the 3D space. Furthermore, by projecting three-dimensional data on a two-dimensional plane it is possible to produce 2D plots to evaluate the criteria for confounding.

Furthermore, Larkin and Sweller suggest that, when images accompany text, understanding and retention of knowledge will generally improve (10, 11). Given our experience in teaching confounding, we expect that 3D data representation may also facilitate the understanding of confounding.

Guideline: Integrate the conceptual and empirical aspect of confounding

Some epidemiological textbooks distinguish the (a priori) conceptual and (data-based) empirical aspect explicitly (1, 2, 12-16) while others do so implicitly (17-23). The conceptual aspect is usually illustrated by examples of exposures, diseases, confounding factors, and non-confounding covariates. Some textbooks summarize the criteria for confounding using causal path diagrams (12, 14, 20, 21, 23-25). The empirical aspect is usually illustrated by examples of crude and adjusted data presented in tables (1, 15, 20, 21) or graphs (22). In this context, stratification and regression analysis are used as tools to assess the presence of confounding and to adjust for it. None of the examples we found in epidemiological textbooks illustrates how confounding can cause reversal of the apparent effect (i.e. the reversal of the sign of the association, the side of the null on which the effect lies) although some books do mention that it is a possibility.

Many students have trouble in connecting the two aspects of confounding when confronted with a real dataset. Therefore, we consider it important to integrate the two aspects of confounding in our teaching. This is achieved, in the 3D LOs, by visualizing that both aspects originate from the same 3D representation of the data. Our method integrates these aspects by illustrating that manipulating the association between the exposure and the confounder results in different crude associations (empirical aspect), although they are derived from the same underlying relationships (conceptual aspect).

<u>Design guidelines based on learning and instruction theories</u>

The most important guidelines for the development of the 3D LOs, based on theories about learning and instruction, are summarized in this section.

Guideline: Actively engage the student in studying confounding

The first guideline is to actively involve the student, because practice is believed to strengthen understanding (11, 26). In the 3D LOs, we will involve students in studying confounding with activities that include answering questions, performing simulations, and projecting data on one surface of the plot. In later applications of these methods we used self-tests to help clarify for students what was most important in the 3D LOs. Using these self-tests, the student could verify whether he understand the meaning of the different characteristics of the 3D LOs by interpreting some other examples of epidemiological data visualized in 3D plots.

Guideline: Use visual methods when possible

A second guideline is to visualize important concepts. Besides visualizing the concept of confounding by using 3D plots, other visual methods are also used in the exercises that accompanied the 3D plots. For example, in the exercises, causal path diagrams are used to emphasize the causal relation between fiber intake, blood pressure and bodyweight.

Guideline: Motivate the students

The last guideline is to motivate the students. Motivation is essential to learning. According to the ARCS model, four factors are essential to motivate the students: Instruction should capture the Attention of the student, it should be perceived as Relevant, and it should induce Confidence and Satisfaction (27). From this principle, guidelines for the design of digital learning material were derived (see Table 1). The attention of the student is drawn by providing novelty (e.g., the 3D plots and several pictures). The relevance of the subject matter is shown by emphasizing the importance of the concept of confounding: the example used in the LOs illustrates the case where failure to adjust for confounding could lead to the conclusion that the effect of an exposure is in the opposite direction of the true relationship. Providing hints and gradually building up the difficulty of the exercises enhances students' confidence and satisfaction in understanding the concepts. For example, in the first 3D LO, several questions with hints are provided while in the third LO students are expected to explore the 3D plot by themselves. This third LO gives also the possibility to test skills that are attained in the first LOs.

Requirements and evaluation

Students evaluated how well the teaching method fulfilled the requirements in the BSc and MSc courses at our university, and in an international PhD course organized by our university. At our university students' perception of the quality of courses, course material and teachers was assessed with standard evaluation forms using agree-disagree questions on a five-point Likert scale. An average appreciation score of 3 on these evaluation forms is considered satisfactory while an average higher than 4 is considered excellent. The 3D LOs were specifically evaluated using such evaluation forms. In addition, exam results of students were analyzed to get an indication of their understanding of confounding.

For the evaluation with experts, evaluation forms with disagree-agree questions on a five-point Likert scale and free response questions were used. The experts worked through the 3D LOs and the exercises as if they were students. They were also asked to focus particularly on whether they think the 3D LOs apply accepted scientific views on confounding. Before this formal evaluation, three of our PhD students and two teachers evaluated the 3D LOs. This resulted in some minor improvements.

Results

Description of the 3D LOs

The following is a description of one of the 3D LO-based lessons we used in our courses. It is based on data from (hypothetical) studies on the relation between fiber intake and blood pressure conducted in three different populations. Body weight is chosen as the potential confounding factor, because it is known to be a risk factor for high blood pressure. We constructed the example so that body weight is not an effect modifier. Each 3D LO starts with a rotatable 3D plot with the outcome (blood pressure) on the y-axis, exposure (fiber intake) on the x-axis, and the possible confounding factor (body weight) on the z-axis. In all the 3D LOs, the values of blood pressure, fiber intake and body weight are chosen so that body weight is a risk factor for high blood pressure and fiber intake is negatively associated with blood pressure. Only the association between fiber intake and body weight differs between the three plots.

In all plots the data can be projected on one side (plane) of the plot, so each plot illustrates:

1. The joint distribution of the three variables together: In all plots visualized by the linear plane fitted to the data (BP = β_0 + β_1 * fiber intake + β_2 * body weight + error) (Figure 1a),
2. That body weight is a risk factor for high blood pressure (β_2) (Figure 1b),
3. The adjusted association between fiber intake and blood pressure (β_1),
4. The association between fiber intake and body weight (differs between the LOs) (Figure 1c),
5. The crude association between fiber intake and blood pressure, illustrated by a regression line through the projection of the data on the fiber–blood pressure side of the plot (Figure 1d),
6. The association between fiber intake and blood pressure stratified for body weight (a slider can be used to highlight only data within a certain stratum of body weight).

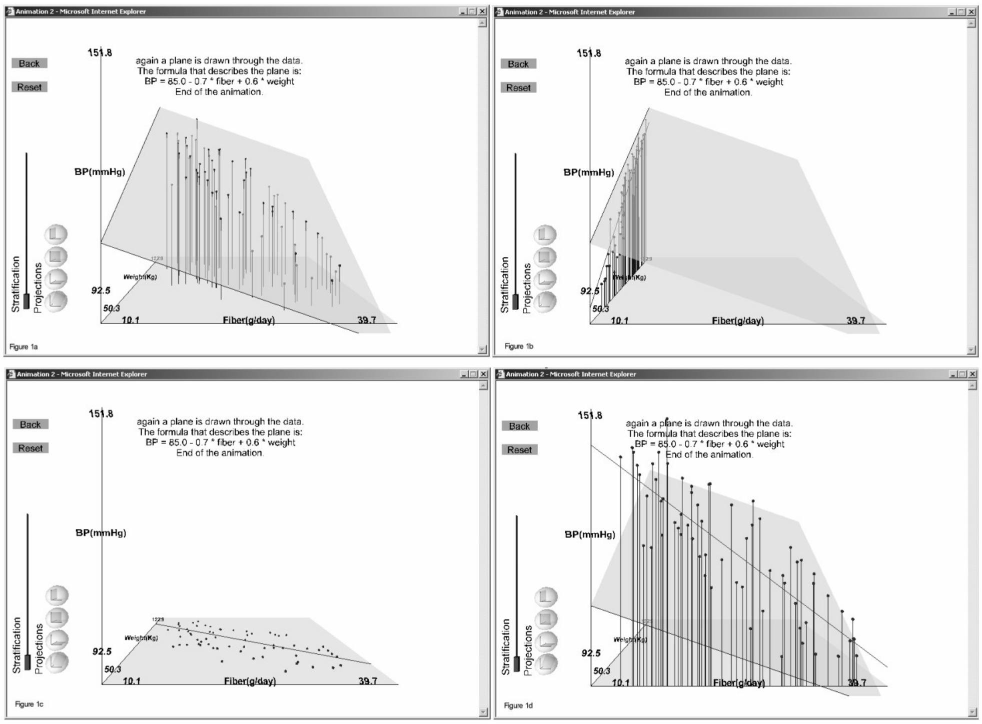


Figure 1: Illustrations of results from the example exercise.
(a) Joint distribution of exposure (fiber intake), effect (high blood pressure), and potential confounder (body weight). (b) Projection of the data on the weight-blood pressure plane: weight is a risk factor for high blood pressure. (c) Projection of the data on the fiber intake–weight plane: fiber intake and weight are negatively associated. (d) Projection of the data on the fiber intake–blood pressure plane: the crude association (the slope of the line) differs from the adjusted association (the slope of the plane).

The learning material consists of three parts, containing a 3D plot and some exercises (Figure 2). Figure 1 shows the main characteristics of the 3D plot as visualized in the second part of the learning material (the second LO). The 3D plot in the first LO represents data from a study in which fiber intake is independent of body weight. This LO illustrates the case where the apparent association between fiber and blood pressure is not confounded by the blood-pressure-increasing effect of body weight. In all LOs we assume that the effect of fiber intake on blood pressure is not mediated by body weight (criterion 3 for confounding (1)).

The second LO (Figure 1) and the third LO show that confounding arises when fiber intake and body weight are associated positively or negatively. For the second 3D LO, subjects with high fiber intake tend to have a lower body weight, perhaps because they are more health conscious. In the second 3D LO, the crude association (the slope of the line resulting from projecting the data to the fiber–blood pressure plane) differs from the adjusted association (the slope of the regression plane, β_1) so body weight is a confounding factor (Figure 1d). The reader can access the second 3D LO presented in this paper, as well as other examples, at our website (28). (See endnote 1 for more information about the website and instructions on how to use the file published with this article which contains a version of what is on the website.)[1]

In the third 3D LO, results of another (hypothetical) study shows how body weight reverses the apparent effect of fiber intake on blood pressure, when fiber intake and body weight are strongly positively associated.

<u>Practical experiences with the 3D LOs and results of evaluations</u>

Evaluation by students:

The 3D LOs are used in our BSc course (104 students, from which 100 filled out the evaluation forms), MSc course (in two subsequent years, in total 44 students) and an international PhD course organized by our university (19 students). Evaluation forms were used to assess the judgments of the students. As indicated in Table 2 the students judged the 3D LOs with a 3.7, 4.5 and 4.2 (on a five-point scale). The value of these student evaluations are limited by the lack of validation of the instrument, a clear definition of what the scores mean, and most importantly, the fact that few of these students had experience learning the material using other teaching tools, so they had nothing to compare this method to. Nevertheless, we interpret the scores as support for the value of this teaching method.

[1] To ensure the existence of a permanent archive, the website that contains the example emphasized in this article has been published with the article as an additional file (however, the website is easier to use, more extensive, and will contain subsequent versions of the software, and thus we recommend readers access it at http://pkedu.fbt.eitn.wau.nl/cora/demosite/ if possible rather than using the additional file). To use the additional file, download the .zip file, unzip it to a folder, and run (double click on) index.html. Note that to run either the web or local version of this demo requires the Macromedia Flash player browser plug-in, which you probably have, as well as a plug-in for viewing 3D images (Cortona from Parallel Graphics) that you will likely need to install. These are free and the index page contains links that will let you install them. We apologize that in its present form, our software will not work with all browsers, security configurations, etc. We recommend the use of Microsoft Internet Explorer and it will be necessary to turn off pop-up blockers. The index page contains a link to check your system's compatibility.

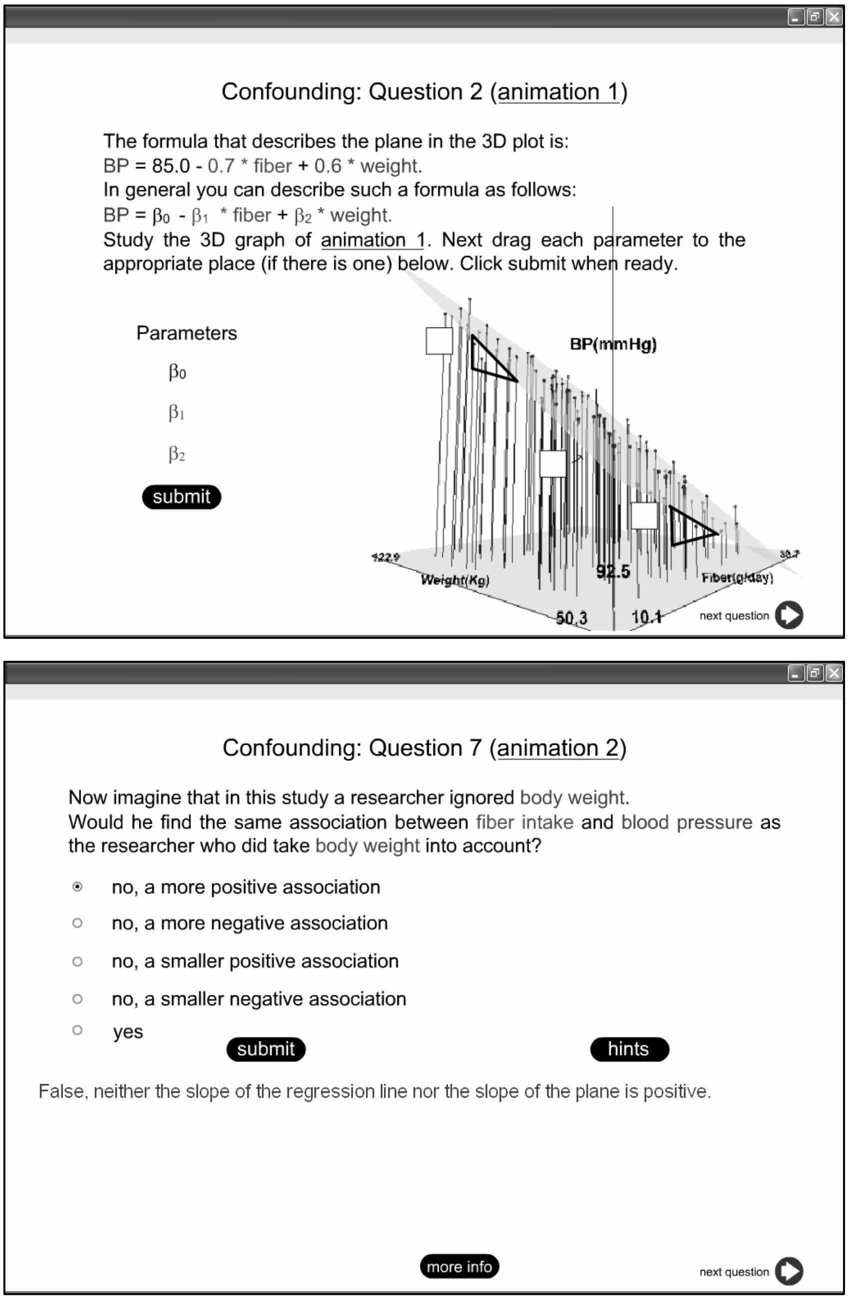


Figure 2: Examples of questions used to help students explore the characteristics of the 3D LOs

To get an indication of the level of competence attained by the students, exam results were analyzed. The exam questions were different for the BSc and MSc course. As indicated in Table 3 the students scored well for the exam; for each question in the BSc course 66% or more of the students gave the right answer. The questions about the integration of the conceptual and empirical aspect of confounding appear the most difficult ones (question 6 and 7). In the MSc course, in two multiple-choice questions descriptions of epidemiological studies must be combined with plots that show the data of the studies. On these questions, respectively 83% and 75% of the students gave the correct answer. Although the same exam questions were not asked in the past, this rating is considerably better than the results from similar exam questions on the same topic that were asked in the past.

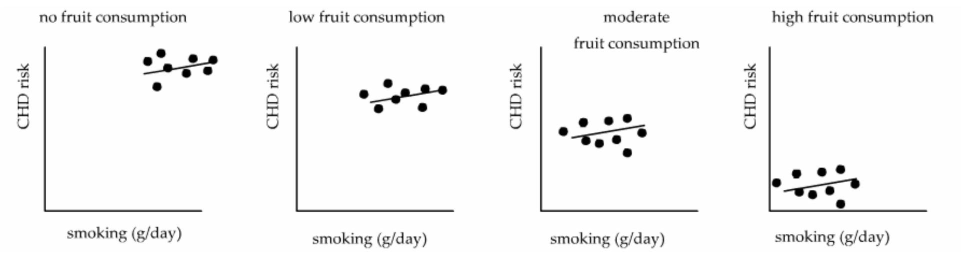
Table 2: Results of evaluation with students.

	Mean score (% with a score of 4 or 5)		
	BSc	MSc	International PhD
Evaluation question*	(n = 100)	(n = 44)	(n = 19)
The 3D plots help me to understand confounding.	3.6 (60)	4.4 (92)	4.2 (89)
It was useful to work with the 3D plots in addition to the lectures and textbook.	3.7 (68)	– †	– †
I enjoyed studying confounding using the 3D plots.	3.4 (53)	4.6 (100)	4.7 (100)
Active handling the 3D plots helps me to understand confounding.	3.5 (52)	4.5 (100)	4.2 (100)
The self-tests were useful.	– ‡	4.6 (100)	– ‡
Overall rating of the 3D plots (1 = poor to 5 = excellent).	3.7 (64)	4.5 (100)	4.2 (95)

*All questions were Disagree – Agree questions with a five-point Likert scale. As indicated an average score of 3 is considered satisfactory while an average higher than 4 is considered excellent.
† In the MSc and PhD course this question was not included on the evaluation form because there was no additional learning material provided about confounding.
‡ Self-tests were only available in the MSc and PhD course.

Table 3: Example of exam question and summary of exam results.

Here, you see results of a study into the association between smoking and risk of coronary heart disease (CHD), stratified for fruit consumption. From scientific research it is known that fruit consumption protects against coronary heart disease.



Questions: multiple choice with 4 possible answers. (The answers are left out this table)	% of students with the right answer.
Which of the plots shows the crude association between smoking and CHD risk?	96
Which of the plots shows the association between fruit consumption and smoking?	75
Which of the plots shows the association between fruit consumption and CHD risk?	94
Which statement is true? (answers contain regression formulas) The crude association between smoking and CHD risk is described by:	81
Which statement is true? (answers contain regression formulas) The association between smoking and CHD risk adjusted for fruit consumption is described by:	70
Which causal diagram gives the representation of the data of this study?	69
Is fruit consumption a confounder or an effect modifier?	66

Illustration of the usefulness of the method to the students came in the MSc course, where students further practiced with 3D plots during the analysis of a cross-sectional study. Most of the students took advantage of the opportunity to consult the 3D LOs again during the data-analysis.

From our experiences in previous years, it seems that during this MSc course students who were taught using the 3D LOs had a better understanding of the concept of confounding and multiple regression as a method to adjust for confounding than previous years (though we concede that this evaluation suffers from the usual problems of non-blinded evaluators who are invested in the outcome). Students asked questions that are more advanced. For instance, many students extrapolated the method to effect modification by describing how a 3D plot would look like in the presence of effect modification.

Since the courses in which the 3D LOs were used and similar courses in which they were not used differ from year to year with respect to specific topics, learning material, form of the exam, number of students, prior knowledge of students, etc., it is not possible to investigate precisely the effect of the 3D LOs (as it would had we been able to do a clean and large scale randomized study). This is a well-known challenge in educational research (29). Therefore, rather than relying too much on the students' demonstrated learning and own evaluations of the methods, we base much of our evaluation on the more indirect method of assessing how well 3D LOs fulfilled the above requirements and how experts evaluated them.

Evaluation by experts in epidemiology:

Eight experts in epidemiology reviewed the 3D LOs; seven were teachers at Dutch universities and one at a non-Dutch university. Six of them filled in the evaluation form while two only responded by giving a general opinion about the 3D LOs. The experts were not involved in the design of or teaching using the 3D LOs. Table 4 summarizes the scores on the evaluation questions. In addition, the experts responded to some open-ended questions. The results suggest that the experts agree that the 3D LOs apply generally accepted scientific views on confounding and should enhance understanding of confounding. However, two experts expressed concern that the 3D LOs would not be helpful for some students who have difficulties with interpreting 3D objects. Three experts suggested that we develop additional learning material explaining the difference between confounding and effect modification. There were also suggestions that the issue of causality in relation to the third criterion (1) for confounding needed further explanation, which we have added (though this change came subsequent to the students' experience with the learning material).

Table 4: Evaluation of the 3D LOs by experts in epidemiology.

Evaluation question*	Mean Score (n=6)
I think the students like the module.	4.3
The questions in this modules where clear and understandable	4.8
It is useful that the 3D plots are rotatable	3.0
The questions in this module are useful	4.8
I think that this module applies general accepted scientific views on confounding	4.5
I think that the use of 3D plots enhanced understanding of confounding by students	4.0
I think that this modules provides a useful addition to epidemiological textbooks and lectures	4.2
I think that this module stimulated the student to study confounding	3.8
I think that this module is useful in my own course.	3.8
Overall rating of the module.	3.8

*All questions were Disagree – Agree questions with a five-point Likert scale.

Conclusion

Recently, other graphical approaches to teaching confounding have been described (30, 31). Unlike our 3D LOs, these approaches address confounding without the use of multivariate regression techniques. Therefore, the approaches could be useful to introduce the concept of confounding and to make the students aware of the importance of considering possible confounders. These approaches do not directly address the relation between the criteria for confounding (conceptual aspect) and the effect of the confounder on the studied exposure-outcome relation (empirical aspect), as do the 3D LOs. Thus, the 3D LOs seem to be more useful at an intermediate level, preparing the students for epidemiological data analysis. Therefore, we think the approaches could complement each other.

Teaching tools using 3D plots are potentially useful in illustrating effect modification, non-linearity in datasets (8), and other relationships of three variables. We plan to design additional learning material contrasting confounding and effect modification. In addition, 3D plots can be useful in teaching other epidemiological principles. For example, how measurement errors in the confounding factor, exposure variable, or outcome variable can lead to, respectively, residual confounding, bias toward the null, or decrease of precision.

Our first experience with the 3D LOs indicate that the integration of the conceptual and the empirical aspect of confounding stimulate the student to think beyond confounding. Although it might be possible that the 3D LOs will not be helpful for some students (e.g. students who have difficulties with interpreting 3D objects) we think that, based on our experiences, the 3D LOs can provide a valuable addition to standard epidemiological textbooks and other graphical presentations of confounding for most students.

Acknowledgments
We would like to thank H van der Schaaf for technical implementation of the 3D LOs, E Kampman, E G Schouten and J Burema for a critical discussion of the 3D LOs during the early stages of the design process and assistance during the evaluation of the 3D LOs. In addition, we would like to thank teachers and experts in epidemiology from outside Wageningen University for critical reviewing the 3D LOs.

Appendix: Application of 3D LOs

<u>Introduction</u>
This appendix describes additional learning material in which 3D LOs are used to assist student in getting experience with the use of linear multivariate regression models to adjust for confounding. This material can be studied next to the 3D LOs described in this chapter. This appendix is meant to illustrate the use of 3D LOs in a data analysis context. The design process largely correspond to the one described in this chapter for the 3D LOs. Therefore a justification of design decisions, a description of the design guidelines and an extended description of the evaluation of the learning material is not provided. Nevertheless, chapter 7 of this thesis provides an overview of the guidelines to discuss similarities and differences between the learning material described in this appendix and the materials described in the other chapters.

<u>Learning objectives</u>
After studying the learning material the student should be able to analyze a specific exposure - outcome relation for a continuous health outcome and should understand the rationale behind a general strategy for these types of analyses.

More specific, the student should be able to detect confounding by simple statistical analysis and to adjust for confounding using multiple linear regression analysis models. Besides, the student should be able to conduct these analyses using statistical analysis software like SAS or SPSS.

<u>The learning material</u>

To assist the students in achieving these learning objectives the learning material presents data from a cross-sectional study on the relation between exposure to paper dust and lung function (32). In the learning material, the student is asked to analyze the association between paper dust exposure and FEV1 (Forced Expiratory Volume in one second). The learning material presents the information and explanations necessary to perform this task and guides the student by interactive exercises, hints and feedback.

Prior to the quantitative analysis, the student is asked to identify potential confounding factors based on information about the causal network that links exposure, outcome and potential confounding factors (the conceptual aspect of confounding). Next, the association between exposure to paper dust, FEV1 and each potential confounding factor is presented in separate 3D plots. From the 3D LOs described before, students learned how 3D plots could be used to determine whether a potential confounding factor is an actual confounder in a data set. However, in this learning material an authentic data set is presented in which confounding is less prominent than in the artificial dataset used in the 3D LOs described before. This implies that a detailed quantitative data analysis rather than visual inspection of regression planes in a 3D space is necessary to determine which variables confound the exposure-outcome relation under study and needs to be accounted for.

Therefore, the learning material presents a general analysis strategy, which can be followed to provide the necessary quantitative data. This analysis strategy is also useful when it is not possible to visualize the data in a 3D plot, e.g. if there is more than one potential confounder. To help the student to understand the rationale behind this general analysis strategy, the strategy is linked to properties of the 3D plots. This is further clarified in Figure 3, which provides an example of an exercise in which the student is stimulated to connect the subsequent steps that are part of the general analysis strategy to properties of the 3D plots. The largest part of this learning material focuses on learning to apply this general analysis strategy.

During this, quantitative data analysis is accompanied by visual inspection of 3D plots. The first part of the analysis (outlined in Figure 3) focuses on obtaining a valid estimate of the association between paper dust and FEV1, free from confounding bias. The second part focuses on improvement of the precision of the estimate by including strong predictors of FEV1 in the regression model. Also in this part, visual inspection of the dispersion of data points around the regression lines and planes in the 3D plots is accompanied by quantitative analysis (calculation of standard errors of regression coefficients, and root MSE and adjusted R-squares of regression models).

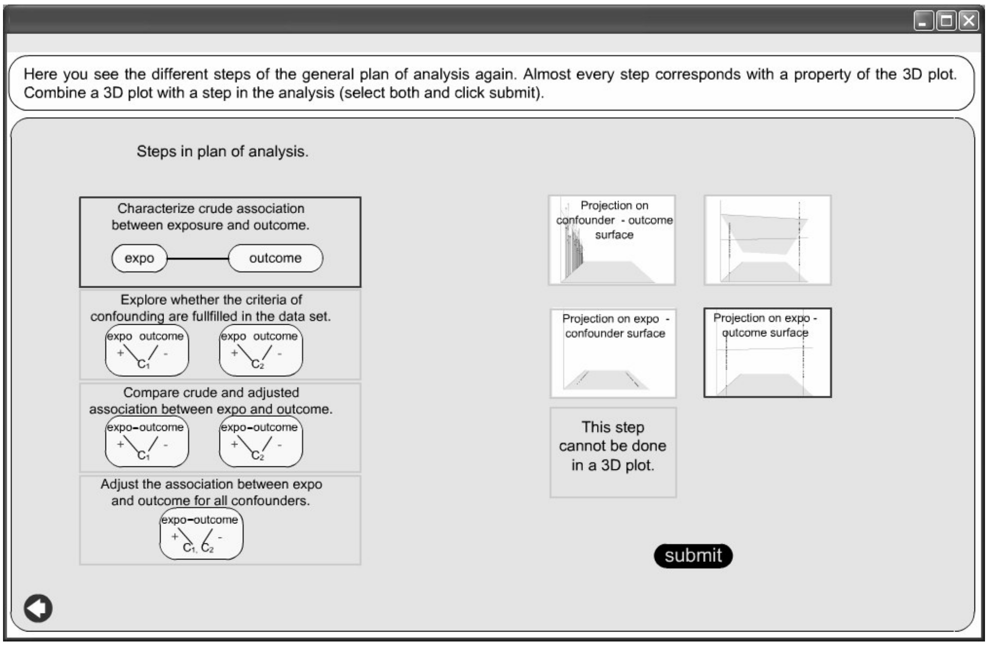


Figure 3: Exercise in which properties of 3D plots are linked to the general data analysis strategy.

<u>Conclusion</u>

The learning material described in this Appendix illustrates that 3D plots could not only be used to explain the concept of confounding as such but that they could also be integrated in learning material that assist students to understand the rationale of epidemiological data analysis in which multivariate linear regression models are used to account for confounding and to obtain a valid as well as a precise estimate of the association between an exposure and an outcome.

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CHAPTER 3

Design of digital learning material on social – psychological theories for nutrition behaviour research

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Abstract

This article describes the design, implementation, and evaluation of digital learning material on the social – psychological Theory of Planned Behaviour (TPB) and its use in nutrition behaviour research.

The design is based on guidelines derived from theories on instructional design. The major component of the design challenge is to implement three design guidelines: (a) the use of concrete examples from the field of nutritional behaviour; (b) the use of Just in Time information presentation according to recent developments in theories about cognitive load; and (c) the promotion of active learning by stimulating the student to activities. These guidelines are designed to be used in the development of learning material that prepares students to apply the TPB in practical cases.

The learning material and its use have been evaluated during two subsequent years in two different academic courses. Initial disappointing evaluation results could mainly be attributed to a discrepancy between design assumptions about the educational setting in which the learning material should have functioned and the actual setting in which the evaluation took place. In a second evaluation, in which the educational setting was adapted to the design assumptions, the learning material satisfied most of the design requirements.

Introduction

The BSc program "Nutrition and Health" at Wageningen University included both an introductory and an advanced course on nutrition behaviour. Until recently, the lectures in the introductory course introduced students to social – psychological theories that helped them to understand the social, psychological and cultural aspects of nutrition behaviour. The final exam in the introductory course tested whether students were able to recall these theories and reproduce their main ideas. Students in the advanced course, however, had to apply the theories taught in the introductory course to case studies on nutrition behaviour. The application of the theories aimed at further developing the advanced students' knowledge through problem-oriented education with decreasing guidance from scientific staff or from well-structured learning material.

In the advanced course it became clear that students were not able to apply the social – psychological theories to nutrition behaviour issues, although they could recall the theories and reproduce their main ideas. Brown *et al*. (1) describe similar situations in which students could recall definitions and concepts or could manipulate algorithms and routines, but had no idea how to use them in authentic situations. They explain this observation by the fact that "teaching methods often try to impart abstracted concepts as fixed, well-defined, independent entities that can be explored in prototypical examples and textbook exercises". We assume that this is also the explanation for our observation that students could recall the theories but could not use them during case studies on nutrition behaviour. Until recently, most of the learning activities in the introductory course were not situated in an authentic nutrition behaviour context but in a general social science context. Furthermore, during the introductory course hardly any stimuli were provided for students to perform activities that involved elaboration on, or application of the described theories. Beyond this, a number of textbooks in social and/or behavioural sciences do not provide stimuli to perform activities, contrary to what many textbooks for other sciences offer (e.g. chapter questions, exercises, quizzes, etc.).

To promote active learning of the social-psychological theories in the introductory course, digital learning material was developed. Digital learning material provides the opportunity to offer powerful stimuli to students to perform actions other than reading literature or attending lectures. Furthermore, using digital learning material makes it possible to use visuals (e.g. interactive diagrams, animations and video clips) which are more elaborate than textbook figures (2). Mayer states, "the promise of multimedia learning is that students can learn more deeply from well-designed multimedia messages consisting of words and pictures than from more traditional modes of communication involving words alone" (3). To promote understanding of social – psychological theories within a nutrition behaviour context, the theories discussed in the introductory and advanced courses are now embedded in a nutrition behaviour context by using appropriate examples and by providing authentic activities. Additionally, the learning material is designed in a way that the same material can be used in different situations with different purposes. In the introductory course the learning material can be used for the purpose of acquiring knowledge about social-psychological theories; whereas, in the advanced course the material can be used to refresh prior knowledge of the same theories.

Topic of the learning material

The topic of the digital learning material is a social – psychological model for predicting and understanding human behaviour: the Theory of Planned Behaviour (TPB) (4, 5). The TPB evolved from the Theory of Reasoned Action (6). The underlying idea of this theory is that nutrition behaviour is quite rational. Therefore, a person's nutrition behaviour (e.g. eating fruit instead of a candy bar) can be predicted by a person's intention to perform that behaviour. A person's intention can be predicted by three components: (a) the person's attitude toward the behaviour, (b) the person's perceptions of what he believes that others think he should do together with his motivation to comply with the wishes of others, and (c) the degree of control a person thinks he has in performing the behaviour. The TPB can be applied to a broad range of human behaviours, including nutrition and health behaviour (7-9).

Intended Learning outcome

After studying the learning material on the Theory of Planned Behaviour (TPB), students should be able to:

- Develop a questionnaire, based on the TPB, which measures social – psychological determinants of nutrition behaviour.

In order to realize this learning outcome, students should also be able to:

- Describe the components of the TPB and the relationships between each of these components.

- Give examples of the components of the TPB that are derived from the field of nutrition behaviour.

Design of the learning material

Assumptions

From a design-oriented perspective, the environment in which the digital learning material functions consists of the educational setting in which the learning material is used (e.g. the course in which the learning material is used, time scheduled to study the learning material, etc.), the computer on which the learning material is used, and the students who use the learning material (e.g. their prior knowledge, their learning processes, their motivation to study the learning material, their computer skills, etc.). The design is based on assumptions about this environment.

When the learning material is used in a course it is assumed that sufficient time is scheduled to study the material. Furthermore, it is assumed that the role of the learning material within the course, and the effort that is necessary to attain the learning goals and to pass the exam are in line with the other parts of the course. The most important assumptions about the prior knowledge of students using the learning material have been described in the introduction. In addition some assumptions are made about the technical facilities that enable the use of the learning material (e.g. the technical specifications of the computers and software). However, it is beyond the scope of this paper to describe all these assumptions in detail.

Goals, guidelines and requirements

A design process is directed by goals, guidelines, and requirements. In instructional design the primary goals are learning goals (10, 11). The learning goals regarding the TPB are described above. In addition to the guideline on learning goals, most attention is given to guidelines aimed at developing learning material that prepares students to apply the TPB in nutrition behaviour research. The main purpose of guidelines is to guide the designer. Evaluating the usefulness of guidelines is partly a matter of evaluating the behaviour of the designer who uses the guidelines. Therefore, in the next paragraphs, the guidelines for the design of the digital learning material are described and illustrated by examples of the learning material to show how the guidelines were used to guide the design.

Besides guidelines, design requirements have been formulated (see Table 1). These design requirements are particularly relevant for the evaluation of the digital learning material within the environment, although most requirements also give direction to the design process. Requirements are formulated in a way that makes it possible to test whether the realized and implemented design meets the requirements once it is in use. To determine whether the design meets the requirements, the learning material needs to be evaluated in an environment that is in agreement with the assumptions about the environment on which the design is based. Sometimes satisfying a specific requirement might imply evidence that a guideline has been followed. However, not every guideline can be evaluated by evaluating a requirement and not every requirement is directly related to a guideline.
According to Weston *et al*. (12), the design of digital learning material should follow guidelines from instructional design theories, subject matter (learning goals), language (semantic issues), and presentation (user interface design). In this article, those guidelines that played a major role in the design of the digital learning material about the TPB are described.

<u>Description of the guidelines and how they have been applied in the learning material</u>

Guideline: Use of concrete examples from research in the field of nutrition behaviour

This guideline is based on subject matter and instructional design theories derived from constructivist principles, which state that learning is achieved by active construction of knowledge. This active construction of knowledge can be supported by providing meaningful, realistic and authentic learning contexts and activities which reflect the way knowledge is used in "real life" (1, 13, 14). For the digital learning material on the TPB, activities with relevance to scientific research in nutrition behaviour are provided. Beyond this, using examples of nutrition behaviour research is important because the intended learning outcome is that students should be able to use the TPB during nutrition behavioural research.

Table 1: Description of requirements, means of evaluation and evaluation criteria.

Requirement	Means of evaluation	Criteria
The TPB is understood after studying the learning material. (C1, C3)	Exam results of students	for exam question[#]
Students are able to answer the exam question which are based on concrete examples from nutrition behaviour research (C1, C3)	Exam results of the students	for exam question[#]
Students think they learned a lot from the digital learning material. (C1, C2, C3, C4)	Question: I think I learned a lot from the digital learning material on the TPB.	for 5-point scale.*
Students feel that the digital learning material was useful with respect to the design of the questionnaire in the working groups. (C2, C4)	Question: The digital learning material on the TPB was useful with respect to the design of the questionnaire in the working groups.	for 5-point scale.*
Students find the digital learning material clear and understandable. (C1, C2, C3, C4)	Question: The digital learning material on the TPB was clear and understandable.	for 5-point scale.*
Students feel that the questions and activities in the digital learning material stimulated them. (C3)	Question: The questions and activities in the learning material stimulated me to study the TPB.	for 5-point scale.*

Requirement	Means of evaluation	Criteria
Students feel that the questions and activities in the digital learning material help them to better understand and remember the TPB. (C3)	Question: The questions and activities in the digital learning material helped me to understand/remember the TPB.	for 5-point scale.*
Students enjoyed the digital learning material. (C1, C2, C3, C4)	Question: I enjoyed the use of the digital learning material on the TPB.	for 5-point scale.*
The general judgment of the digital learning material by students was positive. (C1, C2, C3, C4)	Question: Overall rating of the digital learning material on the TPB (1 = poor to 5 = excellent).	for 5-point scale.*
Students use the JIT information (C1, C2, C3, C4)	Observation of student behaviour.	
Students are able to complete the exercises in the learning material without using additional information besides the JIT information provided by the learning material. (C1, C2, C3, C4)	Observation of student behaviour.	

Mean score > 8 (on a 10-point scale) and less than 10% of the students have a score lower than 6.
* 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)
C1: Requirements evaluated in case study 1 (introductory course 2004).
C2: Requirements evaluated in case study 2 (advanced course 2004).
C3: Requirements evaluated in case study 3 (introductory course 2005).
C4: Requirements evaluated in case study 4 (advanced course 2005).

Furthermore, this guideline aims at motivating students since it is believed that motivated students learn better (11). There are several strategies to motivate students. Essential is that instruction should capture the students' attention, and should be perceived as relevant by the student both with respect to the students' professional future, as with respect to the subject matter (15). To make the learning material more relevant, examples were selected that the students probably recognize in their own life. Therefore, the learning material starts with presenting a nutrition behaviour problem relevant to university students: fruit intake of young people is seldom in line with generally accepted science-based advice, especially during lunches at university canteens. Using this statement, students are asked to develop a questionnaire based on the TPB to determine the reasons why young people in university settings do not eat according to the science-based advice regarding fruit intake. Based on the results of a (virtual) survey with this questionnaire, students develop an intervention strategy to promote fruit consumption at universities. This illustrates the relevance of the TPB for nutrition behaviour research.
Figure 1 shows the first part of the learning material in which the problem is introduced. In the introduction of the material, students watch and interpret video clips of students being interviewed at a university canteen. In the next part of the learning material, they use fragments of the video clips to study the components of the TPB (Figure 3a). In short, the learning material is situated in an authentic nutrition behaviour research context from the very beginning.

Guideline: Use of Just-in-time (JIT) information presentation
The use of JIT information presentation is inspired by the Cognitive Load Theory (CLT) (16-19). The CLT assumes that working memory capacity is limited (20, 21). While performing a learning task, total cognitive load (at a certain moment) is determined by the intrinsic, extraneous and germane cognitive load at that moment. Intrinsic cognitive load is intrinsic to the material being dealt with and cannot be altered by instructional design (16). Germane cognitive load reflects the effort required for storing and organizing knowledge into long-term memory, which requires the processing capacity of the working memory (19). This type of cognitive load is directly relevant to learning. On the other hand, extraneous cognitive load refers to processes that are not beneficial for learning (e.g. combining information sources). Therefore, instructional designs for learning tasks

have to aim at decreasing extraneous cognitive load. Reducing extraneous cognitive load is especially important when a task has the risk of overloading working memory capacity because the cognitive load induced by the intrinsic nature of the learning task is high. The cognitive load imposed by a task depends on the number of elements that must be processed simultaneously in working memory (element interactivity). A task with high element interactivity produces high (intrinsic) cognitive load (16).

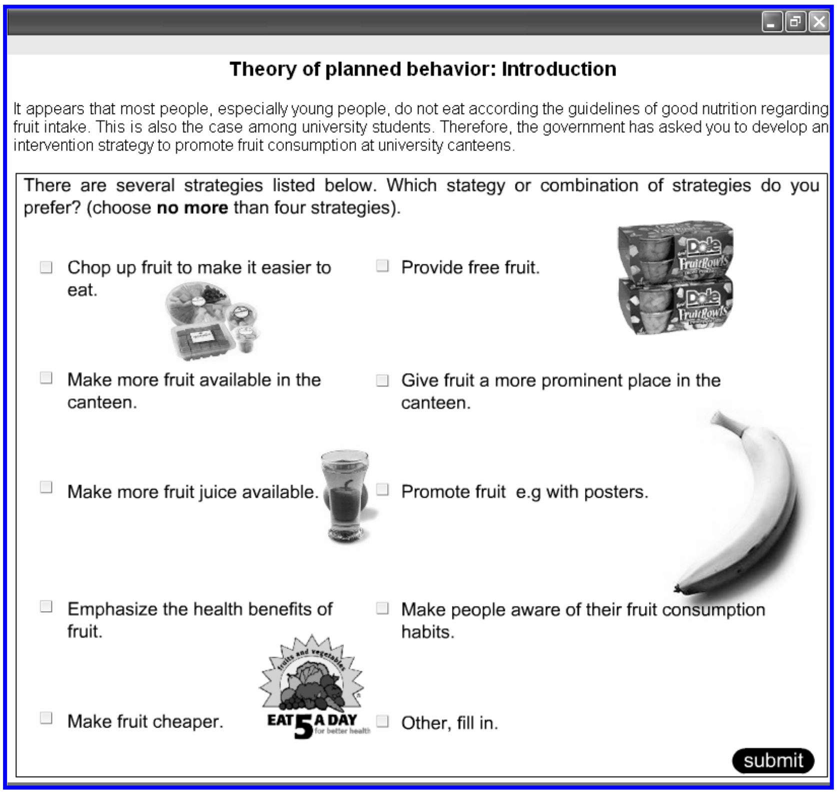

Figure 1a: First part of the learning material.
The purpose of these exercises is to introduce the topic of the learning material to the student by presenting an authentic nutrition behaviour context and by forcing the student to think about the topic (because the student has to answer the questions). For these exercises more than one answer is correct.

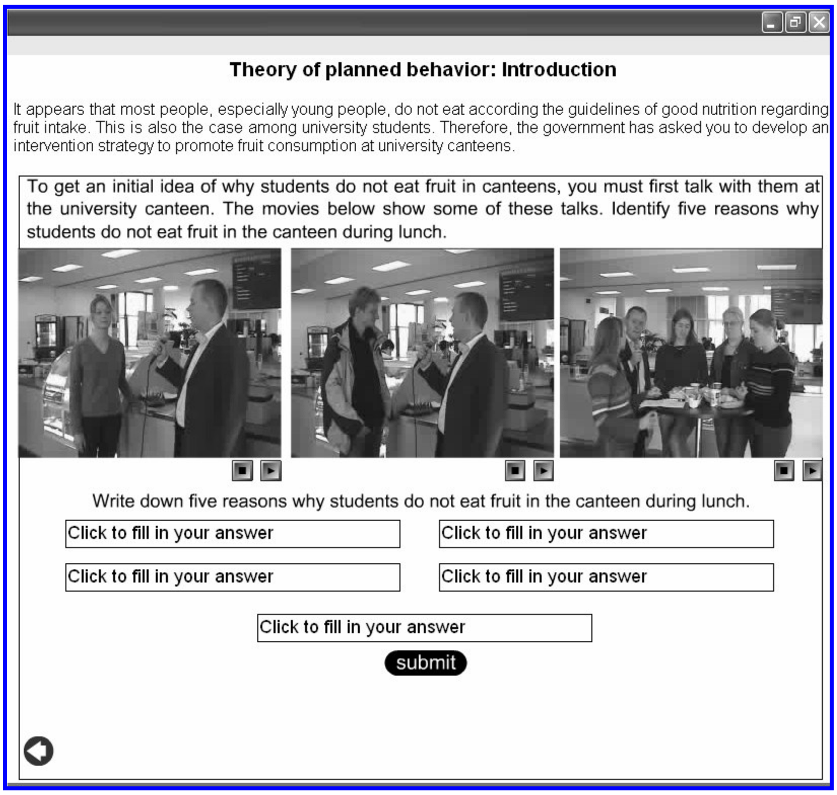

Figure 1a (continued): First part of the learning material.

The primary learning task for students who use the learning material on the TPB is to develop a questionnaire based on the TPB. This task probably produces high cognitive load because the students not only have to keep definitions and examples of the several TPB components in working memory but also the relationship between these components and the requirements that the items of a questionnaire have to satisfy. Additionally, when learning material focuses on authentic and realistic learning tasks, like the TPB learning material, the risk of overloading students' working memory capacity is high (22).

To reduce extraneous cognitive load, JIT information presentation can be used. This means that information (e.g. a key concept, a methodology or a tool) is presented at the time it is required to perform a task. In so doing, the cognitive load required for combining information sources or for searching relevant information is reduced (22-24). Van Merriënboer and Kester describe the optimal timing of JIT information presentation in an instructional design model for complex learning as a method to manage cognitive load while working on a task (22-24). They stated that information supportive to the learning task is best presented before practicing the task and procedural information is best presented while practicing the learning task (see Figure 2a).

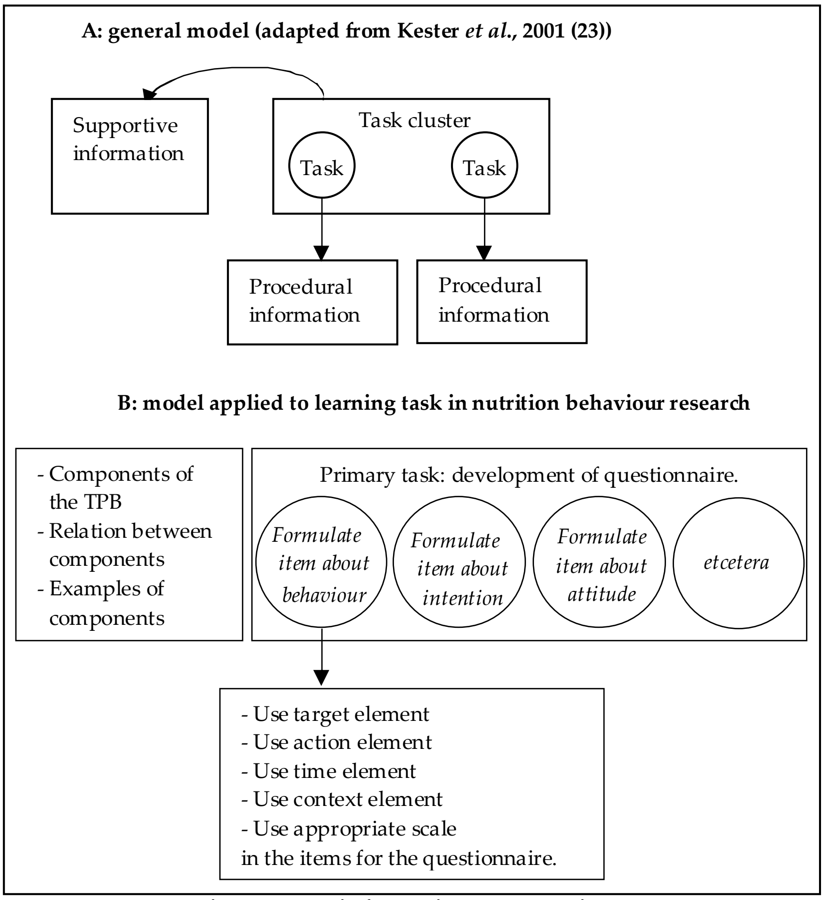

Figure 2. JIT information presentation.

Supportive information usually has a high-intrinsic complexity and is required to master non-recurrent aspects of the learning task, which has to lead to construction of schemata in long-term memory. Once a schema is constructed, it can be held in working memory and act as one single element (16). On the other hand, procedural information is usually information with low intrinsic complexity that is required to master recurrent aspects of the learning task, which has to lead to automatic performance of the recurrent part of the tasks.

To manage students' cognitive load effectively while studying the TPB, the design of the learning material is inspired by Kester *et al*'s model for complex learning. (Figure 2). Performing the primary learning task (development of a questionnaire based on the TPB) requires the formulation of questionnaire items for each component of the TPB. To formulate the TPB's questionnaire, students need to know what the components of the TPB are, how they are related and what their significance is for nutrition behaviour issues. This high-intrinsic complex information is specific and supportive for the learning task (the development of a questionnaire based on the TPB). On the other hand, performing the learning task requires knowledge about how to formulate items for questionnaires. For example, all items have to contain certain elements (an action, a target, a time and a context element) and an appropriate measurement scale has to be chosen. Information about how to formulate items pertains to recurrent aspects of the task (also needed for designing questionnaires based on other theories). As a result of practice, performing these recurrent aspects of the task needs to become routine.

Therefore, information about the different components of the TPB (supportive information) is presented before the primary learning task. This is done by providing various exercises to stimulate the construction of schemata regarding the components of the TPB, their relations and implication for nutrition behaviour research (see Figure 3a for an example). As a result of the exercises, the student will be able to activate this knowledge in working memory while constructing the questionnaire. Information about how to formulate items for questionnaires (procedural information) is provided just in time during the learning task. After receiving the information, students can study it and apply it directly to the learning task (see Figure 3b). Correspondingly, the TPB learning material is divided into several (sub) learning tasks. For each (sub) learning task, procedural and supportive information is identified and provided to the student using JIT information presentation.

Guideline: Promotion of active learning of the TPB by stimulating the student to activities

Active learning is necessary for understanding, acquiring knowledge and retention of knowledge (25). For the design of activities, the interaction types described in the IMS Question & Test Interoperability (QTI) Specification 2.0 are taken as a starting point (26). The main purpose of the QTI Specification is to define an information model that can be used to represent assessment items that enable exchange between authoring tools, item banks and learning systems. However, because the QTI specification describes several interaction types (choice interaction, associate interaction, text entry interaction, hotspot interaction, etc.), this list of interaction types could be used to choose suitable interactions during the development of interactive digital learning material. The figures 1 and 3 illustrate the implementation of different interaction types in the learning material on the TPB, like choice interactions (Figure 1a), text entry interactions (Figure 1b and 3b), and associate interactions (Figure 3a).

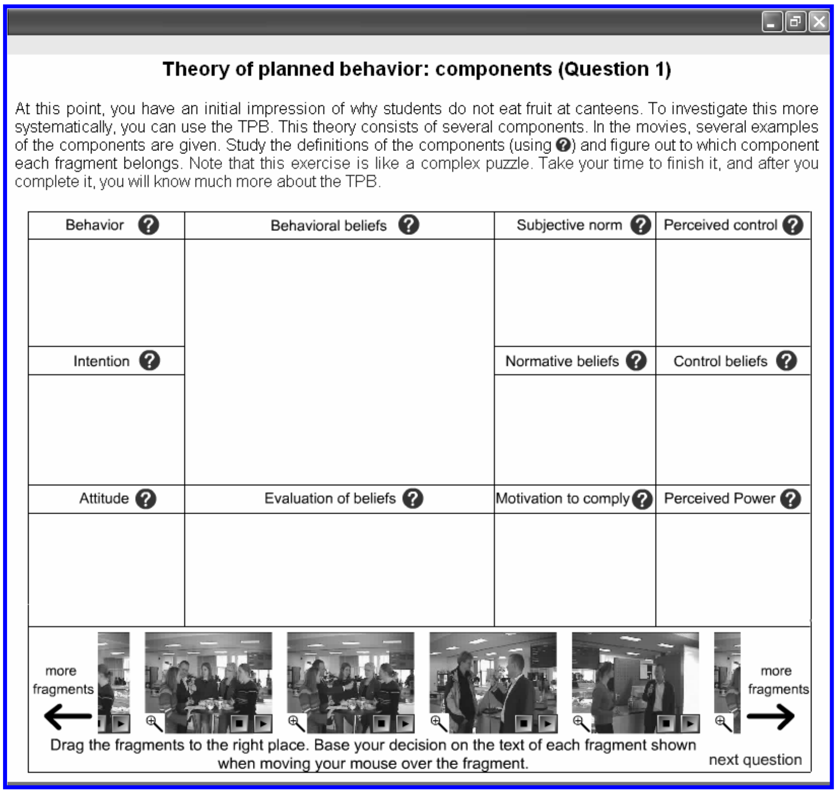

Figure 3a: JIT information presentation

Exercise to study the components of the TPB. The buttons with the question marks provide JIT presentation of the definitions of the components. Each fragment matches to only one of the components.

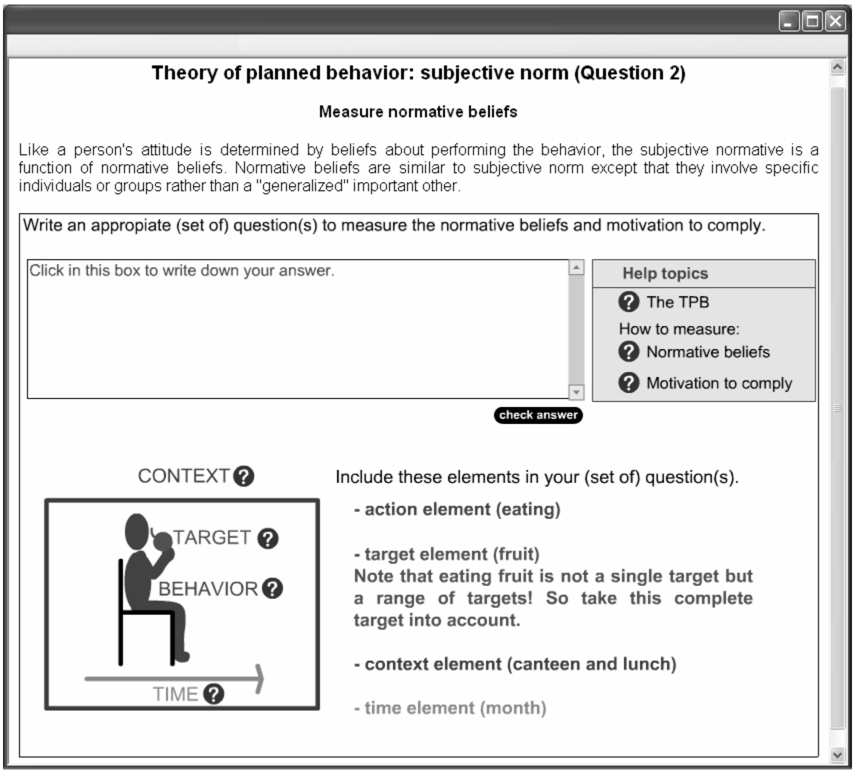

Figure 3b (continued): JIT information presentation
Exercise to formulate a questionnaire item. The help section refers back to the information on the TPB studied before. Information about the elements that need to be included in a questionnaire item is presented just in time. The student can judge his answer and view examples of correct answers by using the 'check answer' button.

Formative evaluation methods

The digital learning material on the TPB was used in four case studies performed in realistic educational settings (Table 2). To get an initial impression of the students' perception of the learning material, it was used in the introductory course (case study 1) of the Nutrition and Health curriculum at Wageningen University in 2004. In addition, the material was used in the advanced course on nutrition behaviour that same year (case study 2). Students who followed the advanced course had not previously studied the digital learning material on the TPB. They only attended lectures about the TPB given in the introductory course, because at the time these students took the introductory course the digital learning material was not yet available. In addition to studying the digital learning material, students in the advanced course further expanded their knowledge on the TPB by performing several nutrition behaviour studies. One of these studies included the development of a questionnaire based on the TPB.

In case study 1 and 2, students completed a short evaluation form (5 questions) with agree-disagree questions on a five-point Likert scale. These evaluation forms are conform standard evaluation procedures at the university. The questions refer to the requirements related to student perception of the digital learning material

Furthermore, in the introductory course, exam results of the students were analyzed to evaluate whether the students attained the learning goals of the learning material as described before. The exam question about the learning material consisted of three sub questions. The first sub question asked students to recall the Theory of Planned Behaviour by means of a schema. The second sub question asked the student to give an example of the components of the TPB (related to a nutrition behaviour topic). The last sub question asked to formulate items for a questionnaire based on the TPB.

During the hours which were scheduled to work on the learning material, the designer of the learning material was present to answer questions of the students and to identify shortcomings of the learning material. In addition, during studying the learning material, students were asked to report everything that was not clear or that was perceived as extremely difficult. After the evaluation in case study 1 and 2, parts of the digital learning material were revised.

A more extensive evaluation was conducted for both courses in 2005. In the introductory course (case study 3), students studied the learning material, completed a more extended evaluation form, and answered exam questions. In the advanced course (case study 4), the learning material was offered to the students in order to stimulate them to refresh their prior knowledge. The students in case study 4 also completed a short evaluation form.

Table 2: Timing of activities in the case studies.

	Case study 1 Introductory course	Case study 2 Advanced course	Case study 3 Introductory course	Case study 4 Advanced course
Activities	**Weeks in which activity took place † Time attributed to each activity ***			
Introduction lecture TPB	-	-	(wk 1) 2 h	(wk 1) 2 h
Digital learning material TPB	(wk 2 & 3) 3 h/wk Total 6 h	(wk 2) 4 h Total 4 h	(wk 1- 6) 2 h/wk Total 12 h	(wk 2) 4 h Total 4 h
Lectures "nutrition behaviour research"‡	(wk 1-6) 4h/wk	(wk 1) 6h	(wk 1-6) 4 h/wk	(wk 1) 6 h
Problem-oriented education - related to TPB - other topics ‡	(wk 1-6) - 2h/wk	(wk 1-6) 3h/wk 6h/wk	(wk 1-6) - 2h/wk	(wk 1-6) 3h/wk 6h/wk
Example exam questions	-	n.r.**	(wk 6) 2 h	n.r**
Self-study digital learning material TPB (in total)	4-10 h	2-6 h	10-15 h	2-6 h
Exam#	(wk 8) 4 h	n.r.**	(wk 8) 4 h	n.r.**

* Each case study was conducted within an eight week course. It was assumed that students spent 50% of their time on this course and the remaining 50% of their time on other courses in their curriculum.
† The table only shows scheduled time for each activity. In addition to this scheduled time, it was assumed that students studied the digital learning material, the topics of the lectures and the topics of the problem-oriented education on their own.
‡ The lectures and topics for problem-oriented education were not directly related to the TPB but covered other theories in nutrition behaviour research.
# The seventh week of each course was reserved for exam preparation or for finishing reports on topics for the problem-oriented segment of the course.
** Not relevant, because the main goal of using the learning material in the advanced course (case study 2 and 4) was to refresh prior knowledge. This was not evaluated by means of an exam.

Evaluation results and discussion

Evaluation of the learning material in the first two case studies suggested that the learning material did not meet all design requirements. Students did not fully enjoy studying the learning material and did not think they learned much. They rated the learning material with a 2.7 (case study 1) and a 3.3 (case study 2) on a five point scale (see Table 3). In addition, the exam scores of 74% of the students in the first case study were not satisfactory (see Table 3). From the exam results it became clear that 80% could recall the TPB using a schema. 30% of the students

were able to give examples of the components of the TPB and only 11% of the students could formulate items for a questionnaire based on the TPB.
Investigation of the environment, in which the first two case studies were conducted, revealed some discrepancy between the design assumptions about the environment and the environment in which the case studies actually took place. It was hypothesized that the disappointing evaluation results could be attributed to this discrepancy. Consequently, for the third and fourth case study, the environment in which the evaluation took place was adjusted to remove this discrepancy.

Table 3: Evaluation results.

Requirements	Case study 1 (n = 46)	Case study 2 (n = 41)	Case study 3 (n = 49*)	Case study 4 (n = 35)
	Mean score (% with a score of 6 or less)			
Exam results (10-point scale)	5.0 (74%)	n.r.†	7.9 (9%)	n.r.†
Evaluation question (5-point scale)	**Mean score (% of students with a score of 4 or 5)**			
I think I learned a lot from the digital learning material on the TPB.	2.7 (16)	3.0 (33)	3.6 (69)	4.0 (75)
The digital learning material on the TPB was useful with respect to the design of the questionnaire in the working groups.	n.r. ‡	3.2 (44)	n.r. ‡	3.7 (73)
The digital learning material on the TPB was clear and understandable.	2.8 (19)	3.3 (51)	3.6 (61)	4.0 (80)
The questions and activities in the learning material stimulated me to study the TPB.	-	-	3.3 (47)	-
The questions and activities in the learning material helped me to understand the TPB.	-	-	3.9 (82)	-
The questions and activities in the learning material helped me to remember the TPB.	-	-	3.6 (63)	-
I enjoyed the use of the digital learning material on the TPB.	2.5 (23)	3.3 (45)	2.5 (14)	3.5 (60)
Overall rating of the digital learning material on the TPB (1 = poor – 5 = excellent).	2.7 (13)	3.3 (49)	3.3 (43)	3.8 (80)

* 49 of the 52 students who followed the course filled out the evaluation form.
† Not relevant, because the main goal of using the learning material in the advanced course (case study 2 and 4) was to refresh the prior knowledge of the students. This was not evaluated by means of an exam.
‡ Not relevant because the introductory course did not contain working group assignments on the TPB.

The first assumption regarding the educational setting was that the scheduled amount of time was sufficient to study the digital learning material at least once. Students in the first two case studies complained that they did not have enough time to study the learning material. Students in the advanced course (case study 2) probably had fewer problems with the insufficient time scheduled than students in the introductory course (case study 1) because they had some prior knowledge of the TPB and only used the learning material to refresh their knowledge. This could explain why students in the advanced course evaluated the learning material with a higher score than students in the introductory course. Based on these observations it was concluded that the first assumption was not fulfilled. Consequently, during case study 3, students were given more time to study the material.

The second (implicit) assumption was that students were aware of the learning goals and the corresponding necessary study effort. Although the learning goals were mentioned in the learning material, from personal communication with the students in case study 1, it became clear that students underestimated the effort necessary to reach these learning goals and to pass the exam. Students studied exams from previous years to get an idea of the content of the exam, but these exams only tested whether students could recall the TPB by reproducing a schema that describes the TPB. The current exam achieves the overall learning outcome described in the first part of this article by asking for examples of the different components of the TPB from nutrition behaviour research and by asking to formulate items for a questionnaire. These tasks require a deeper understanding of the TPB than simply the ability to reproduce a schema. Therefore, in case study 3, in order to prepare the student for a different type of exam, a self-test was provided with examples of exam questions to inform the students with respect to content and question types of the exam. In addition, an introductory lecture was given to correct misconceptions about learning goals and expected study load. In the introductory lecture in the advanced course (case study 4), students were informed of the possibility to study only parts of the digital learning material in order to refresh their prior knowledge about the TPB.

Other explanations of the low evaluation scores in case study 1 and 2 could possibly be found in other parts of the environment in which the evaluation took place (e.g. the prior knowledge of the students or the computers on which the learning material was used) or in the learning material itself. However, there are

no concrete indications that other parts of the environment or the nature of the learning material itself caused this low evaluation score.
From the remaining two case studies (case study 3 and 4) in which the educational setting was adjusted, conform the assumptions on which the design of the learning material was based, it seems that the learning material meets most of the requirements described in Table 1. The students in the introductory course (case study 3) think they learned a lot from the learning material (score of 3.6 on a five – point scale). In addition, the exam results of 81% of the students were satisfactory. From the exam results it became clear that 83% could recall the TPB using a schema. 96% of the students were able to give examples of the components of the TPB and 55% of the students could formulate items for a questionnaire based on the TPB. The students rated the learning material with an average score of 3.3 (for case study 3) and a 3.8 (for case study 4) on a five-point scale. These evaluation results were in line with the hypothesis that the initial disappointing evaluation results of the first two case studies could mainly be attributed to a discrepancy between the design assumption about the environment in which the case studies took place and the actual environment in which the case studies were conducted.
In addition, the designer who was present during the scheduled hours, observed that most students were able to complete the exercises using the JIT information provided by the learning material (see for example Figure 3b). The students did not need additional information from the designer who was present to supervise the students. Most students actually did study the JIT information during the exercises which were provided by the digital learning material. For example, during the exercise shown in Figure 3b most students first tried to formulate a rough version of the answer by themselves. After that, they studied part of the JIT information provided by the hyperlinks and adjusted their question based on what they learned from this information. After adjustment of their answer, they studied another part of the JIT information until they were satisfied with their answer. When satisfied they did check their answer by using the feedback and the example answer that was provided by the learning material. These and similar observations, give a first indication that the behaviour of the students was in line with expectations based on the principles of cognitive load and Just in Time information presentation.

Conclusion

Activating digital learning material on the TPB has been designed, developed, implemented and tested. The design is based on design guidelines and design requirements derived from subject matter and theories on cognitive science and instructional design. Previous research suggested that these guidelines are useful in developing learning material for sciences like epidemiology (27) and food chemistry (28). The digital learning material on the TPB shows how the cognitive load theory can be applied to further articulate and clarify design guidelines with respect to Just in Time information presentation.

At the same time, identifying supportive and procedural information, and separating supportive from procedural information conform the cognitive load theory, is not trivial. Examples that further clarify the meaning of core concepts of the cognitive load theory in a practical instructional design context are still scarce. For the digital learning material, authentic learning tasks were defined and supportive and procedural information for these tasks were identified. Encapsulating this information in learning objects that allow for JIT presentation enables novices to engage in learning tasks situated in an authentic context. Initial disappointing evaluation results were attributed to the fact that the actual educational setting in which the evaluation was conducted did not satisfy the design assumptions about the educational setting. In the second evaluation, in which the educational setting was adapted to the design assumptions, the learning material satisfied the design requirements. The exam results indicated that most students (81%) reached the learning goals of the learning material.

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CHAPTER 4

Design guidelines for the development of digital nutrigenomics learning material for heterogeneous target groups

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Abstract

Nutritional genomics or nutrigenomics can be considered as the combination of molecular nutrition and genomics. Students who attend courses in nutrigenomics differ with respect to their prior knowledge.

This paper describes digital nutrigenomics learning material suitable for students from various backgrounds, and provides design guidelines for the development of the learning material. These design guidelines, derived from theories on cognitive science and instructional design, describe the selection of interaction types for learning tasks and the timing of information presentation.

The learning material supports two learning goals: first, the formulation of meaningful research questions in the field of nutrigenomics and second, the development of feasible experiments to answer these questions. The learning material consists of two cases built around important nutrigenomics topics: (a) personalized diets and (b) the role of free fatty acids in regulation of hepatic gene transcription. Each case consists of several activities to promote active learning by the student. Evaluation of the cases in a realistic academic educational setting indicates that the cases were useful.

Introduction

Traditionally, nutrition research has primarily focused on nutrient deficiencies and the relation between nutrition and health. The advent of genomics -interpreted broadly as a suite of high-throughput technologies for the generation, processing, and application of scientific information about the composition and functions of genomes- has created unprecedented opportunities for increasing our understanding of how nutrients modulate gene and protein expression and ultimately influence cellular and organismal metabolism. Nutrigenomics, the combination of molecular nutrition and genomics, studies the genome-wide influence of nutrition in order to unravel the mechanisms underlying the physiological and molecular effects of nutrients (1). It aims to promote an increased understanding of how nutrition influences metabolic pathways and homeostatic control, how this regulation is disturbed in the early phases of diet-related disease, and the extent to which individual sensitizing genotypes contribute to such diseases. Eventually, nutrigenomics will lead to evidence-based dietary intervention strategies for restoring health and fitness and for preventing diet-related disease.

Teaching nutrigenomics.

Nutrigenomics is relevant for students of several study programs. For example, at Wageningen University, bachelor and master students of the nutrition and health curriculum, the biotechnology curriculum and the biology curriculum attend the introductory course in nutrigenomics. In general, students of the nutrition and health curriculum have knowledge of nutrients and their physiological effects but lack understanding of molecular biology, genetics and genomic techniques. These students attend the nutrigenomics course to acquire some basic knowledge about the molecular mechanisms that underlie the physiological effects of nutrients. On the other hand, students of the biotechnology curriculum have prior knowledge about molecular and genomic techniques and mechanisms but lack knowledge of nutrients and their physiological effects. These students are interested in the nutrigenomics course to gain understanding of the molecular effects of nutrients. During the first years in which this course was taught, it became clear that most lectures did not match the need of all these students. It seems almost impossible to instruct all students at once, without boring one group or making it too complex for another group. A solution for this problem would be to instruct the different student groups separately, at least for part of the lectures. However, this runs the risk that students focus on one content area, thereby losing track of the multidisciplinary nature of nutrigenomics. Another problem of the current nutrigenomics course was that, until recently, the course consisted mainly of lectures and a small laboratory assignment, which caused students to complain that there were insufficient opportunities to be actively involved in studying nutrigenomics.

Furthermore, since nutrigenomics is a relatively new scientific discipline, few nutrigenomics textbooks are available which could be used to teach nutrigenomics. Most available textbooks consist of contributions of several authors from the field of nutrigenomics or related fields and target an audience consisting of advanced students and researchers (see for example (2-4)). Without extensive prior knowledge of different content areas, including nutrition, genomics, physiology, endocrinology and molecular biology, the contributions are difficult to follow. Accordingly, these books are inappropriate for an introductory course in nutrigenomics attended by a heterogeneous group of students. Alternatively, textbooks on genetics, genomics, physiology or nutrition could be used to obtain the necessary knowledge. However, again this runs the risk that students loose track of the multidisciplinary nature of nutrigenomics. The same limitations apply to available audiovisual and interactive materials.

Consequently, there was a need for new learning material or a new educational approach for the nutrigenomics course that had to be suitable for teaching nutrigenomics to a heterogeneous target group. To fulfil these needs, new interactive digital learning material was developed with the specific aims to introduce the subject of nutrigenomics, to emphasize the multidisciplinary nature of nutrigenomics, to reduce the problem of a heterogeneous target audience and to stimulate involvement of students in studying nutrigenomics and nutrigenomics research. This paper describes the digital learning material, its design, development, implementation and evaluation in order to provide guidance for successfully introducing interactive digital learning material for teaching nutrigenomics or related scientific disciplines.

Material and Methods

The learning material was designed during an iterative process. This process included the formulation of learning goals and objectives, the selection of topics for the learning material, the structuring of learning tasks and information on the topics, the implementation of human-computer interactions (i.e. interactive exercises) and the (formative and summative) evaluation of the learning material. Guidelines were formulated to direct the design of the learning material. The guidelines are derived from theories on learning and instruction (Table 1). Most guidelines have been described before (5, 6). Next to guidelines, requirements were defined. Besides directing the design process, requirements are particularly relevant for the evaluation of the learning material and to test whether the final design meets the requirements once it is operational. The requirements are consistent with the guidelines (see Table 1). The next paragraphs describe the main phases in the design process and illustrate how the guidelines and requirements directed the design process.

Formulation of learning goals and objectives

The formulation of the learning goals and objectives is an important part of the design process (7). For the design of the learning material for nutrigenomics, two learning goals were defined focusing on the formulation of meaningful research questions and the design of feasible experiments in the field of nutrigenomics (see Table 2). These learning goals are chosen because the expectations of (part of) the scientific community and of society in general about what nutrigenomics can accomplish in relation to nutrition, health and disease are often unrealistic. Therefore, it is important that the student learns about the opportunities and limitations of nutrigenomics research and is trained how to break down a complex nutrition related problem into smaller research questions that are amenable to actual experimentation. Moreover, by stimulating the student to think about meaningful research questions and feasible experiments, active learning is stimulated (guideline 4). In addition, it prepares the student for future academic work.

To achieve the learning goals, the student needs to acquire and use knowledge about various nutrigenomics related subjects. For each learning goal, this knowledge is articulated in several learning objectives, stating what a student should be able to know or to do after completion of (a part of) the learning material. Together, the learning goals and objectives describe the intended learning outcomes supported by the learning material.

Topic selection

For the selection of the topics covered by the learning material the learning goals and objectives (guideline 1) and the necessity to motivate the student (guideline 2) played an important role. According to the ARCS model of Keller (8), four factors are essential to motivate the students: Instruction should gain the Attention of the student, it should be perceived as Relevant, and it should induce Confidence and Satisfaction. For the topic selection, the first two factors of the ARCS model are most relevant. The attention of the student can be gained by starting with a puzzling question or an actual or controversial problem. Therefore, the main part of the digital learning material consists of two cases build around an actual or motivating topic, relevant for nutrigenomics research, to get the attention of the student and to show the relevance of nutrigenomics research. Together, the two cases cover the learning goals as described in Table 2.

The topic of the first case is “personalized diets”. In this case, personalized diet means a dietary advice specifically tailored to a person’s individual need as determined by his genetic profile (the presence or absence of certain gene polymorphisms). This is a relevant topic, as our society in general is becoming increasingly obsessed with diets and a healthy lifestyle. What is still unclear is whether this growing awareness about the importance of healthy eating behaviour, when coupled with major technological advances in genetic screening, will drive a completely novel approach towards nutritional education. Would it be possible that you go to your supermarket, have a drop of blood analyzed and receive an individually tailored shopping list? In this first case the student discovers what is feasible given the state of the art in nutrigenomics and what can be expected in the future with regards to personalized diets.

Table 1: Guidelines, requirements and evaluation questions.

no	Guidelines	no	Requirements	Evaluation questions*
g1	Focus on the learning goals.	r1a	Students are able to answer exam questions related to the learning goals.	n/a †
		r1b	Students indicate that they learned a lot from the learning material.	I learned a lot from this case.
		r1c	Students are able to recognize the main learning goals in the cases.	This case presents me with a clear example of …#
		r1d	Experts confirm that scientific quality of the material is sufficient.	n/a ‡
g2.	Motivate the student.	r2	Students indicate that the components that require them to become active learners motivate them to study.	The questions and activities raised my motivation to study.
g3	Use JIT information presentation.	r3	Students indicate that the digital learning material is clear and understandable.	The exercises have been clearly formulated. The feedback given on my answers was clear. The case links up well with what I already know
g4	Promote active learning.	r4	Students indicate that the questions and activities in the digital learning material forced them to become an active learner.	It is good that the questions and activities forced me to become an active learner.
g5	Visualize important concepts when possible.	r5a	Students indicate that that the visualizations helped them to understand important concepts.	The visual aspects in this case helped me to understand important concepts.
			Experts confirm that the visualization of important concepts is in keeping with their own understanding of these concepts	n/a ‡
		r5b	Experts in nutrigenomics confirm that the screen layout, colors, pictures etc are adequate.	n/a ‡

no	Guidelines	no	Requirements	Evaluation questions*
			General requirements	
		r6	Students enjoyed the digital learning material.	I enjoyed studying this case.
		r7	The general judgment of the digital learning material by students was positive.	Overall rating of the case (1 = poor – 5 = excellent).
		r8	Experts in nutrigenomics confirm that the general pedagogical approach is adequate.	n/a‡
		r9	Experts in nutrigenomics confirm that the navigational aspects are adequate.	n/a‡
		r10	Experts in nutrigenomics confirm that the texts of the cases is clear.	n/a‡

* Evaluation questions use a five point Likert scale (1=totally disagree, 2=partially disagree, 3=neutral, 4=partially agree, 5=totally agree). Requirements are considered to be fulfilled when average rating is 4.0 or more and at least 75% of the students rate a 4 or 5.

† This requirement is evaluated by analyzing students exam results. Exams are scored on a 10-point scale. Requirement r1a is considered to be fulfilled when mean score is greater than 8 and less than 10% of the students have a score lower than 6.

‡ This requirement is evaluated by experts in nutrigenomics using several evaluation questions and interviews.

#(for case 1) nutrigenomics research, (for case 2) a nutrigenomic experiment.

Table 2: learning goals, objectives and learning task of the digital learning material.

Learning goal 1	After studying the learning material the student must be able to … formulate meaningful research questions in the field of nutrigenomics.
Objectives 1*	… explain similarities and differences between nutrigenomics, nutrigenetics, pharmacogenomics, toxicogenomics. … explain associated problems and challenges of transcriptomics, proteomics and metabolomics. … explain the physiology of nutrition-related diseases like obesity, diabetes I and II, metabolic syndrome and cancer. … explain the digestion, storage and associated signaling pathways of the most important nutritional signals (micro/macro nutrients). … evaluate the importance and give examples of nutrigenomics research. … discuss what is feasible with respect to “personalized diets” and other nutrigenomics related topics.
Learning goal 2	… develop feasible experiments to study nutrigenomics research questions by using molecular tools/techniques (Within time and money constraints).
Objectives 2*	… formulate meaningful research questions (and hypothesis) for a nutrigenomics problem. … explain the function of the nuclear receptors PPARα,β,γ, RXR/RAR, RXR, LXR, SREBPγ, SREBP2. … choose from a set of tools and techniques, techniques for an experiment in order to answer a specific research question. … interpret and critically discuss results of micro array experiments.
Learning task 1	Give arguments whether you think “personalized diets” is something nutrigenomics research will bring or whether it is just science fiction.
Part-tasks	1) Discuss whether commercially available personalized diets advice is indeed PERSONAL (by comparing them to dietary guidelines, separately for macro- and micro- nutrients). 2) Discuss whether screening for less than 25 SNPs is sufficient to give a diet advice. 3) Give opinion about the role of nutrigenomics in the development of personalized diets (what is feasible and what not).
Supportive information *	1) Nature of the commercially available personalized diets, examples of macro- and micro- nutrients etc 2) Metabolic pathways in which the genes MTHFR, PPARg, GSTM1, IL6, VDR and ApoC3 are involved, role of these genes in health and disease etc 3) Goals and strategies in nutrigenomics research, definitions of transcriptomics, proteomics and metabolomis etc
Formally redundant information*	The student had to understand the following concepts: SNPs, transcription factors, gene transcription and translation. The student had to know the function of the most important nutrients and foods which contain these nutrients The student had to know the general guidelines for good nutrition.

Learning task 2	Design a nutrigenomics experiment to investigate the role of free fatty acids on gene transcription in the liver (to understand more about obesity).
Part-tasks	1) Formulate research question and hypothesis. 2) Design an experiment by selecting study objects, experimental treatments, tools and techniques. 3) Interpret the results of the experiments.
Supportive information*	1) Information about physiology of obesity, fatty acids and gene transcription in the liver, etc 2) Information about transgenic animals, methods to measure transcriptome, proteome etc. 3) Experimental results, information about micro-array experiments.
Formally redundant information*	The student had to understand the following concepts: Obesity (BMI), transcription factors, northern- and southern blot, PCR etc.
Procedural information	The student had to be able to search databases of the "National Centre of Biotechnology Information"(NCBI) The student had to be able to find information about e.g. transgenic animals (site of the Jackson laboratory) and micro arrays (site of Affymetrix)

* Only some examples of objectives, supportive information and "formally redundant" information are given.

The topic of the second case is obesity. According to the World Health Organization, obesity has reached epidemic proportions globally, with more than 1 billion adults overweight (at least 300 million of them clinically obese), and is a major contributor to the global burden of chronic disease and disability (9). Therefore, obesity is a relevant topic for students to focus on. To motivate the student, he takes the role of an MSc student who performs nutrigenomics research on the subject of obesity. A virtual professor is available throughout the case to guide the student. During this case, the student will design and analyze an authentic nutrigenomics experiment. While performing this experiment in the laboratory would be expensive and would require advanced laboratory skills, this case gives the student the opportunity to develop competencies in planning and analyzing a nutrigenomics experiment without extensive laboratory experience.

<u>Structuring of task practice</u>

To identify and structure learning tasks for the digital learning material, the Four Component Instructional Design model (4C/ID) of van Merriënboer is used (10, 11). The 4C/ID model offers a structured design approach for complex cognitive skills. The four components of instructional design which are distinguished by the 4C/ID model are: Whole-task practise, Part-task practise, Supportive information (information that teachers typically call “the theory” and which is often presented in study books and lectures) and Procedural information (12). Each component will be further addressed in the next paragraphs.

For each case, learning tasks were derived from the learning goals and the topic of the case (see Table 2). The learning task for case 1 is to provide arguments in support of or against the concept of personalized diets. The learning task for case 2 is to design a nutrigenomics experiment addressing the role of free fatty acids in regulation of gene transcription in the liver (in order to understand more about the etiology of obesity).

These learning tasks cover the complex cognitive skills that student needs to acquire. According to van Merrienboer, complex cognitive skills are skills which are complex in the sense that they comprise a set of constituent skills (of which the majority is in the cognitive domain) and at least some of those constituent skills involve conscious processing (10). Because one of the characteristics of complex cognitive skills is that they are hard to learn, the learning tasks were analyzed and decomposed into several part-tasks that are less complex.

To identify for each learning task the relevant part-tasks, the mental and physical steps that the student must go through to complete the learning task were identified. As suggested by Smith and Ragan (7), this was done by discussing the learning task with experts in nutrigenomics, by identifying the main steps they take and decisions they make and by gathering information about the learning task in scientific literature and study books. Table 2 gives a comprehensive overview of the results of the decomposition of the learning task (or complex cognitive skills) into its part-tasks (or constituent cognitive skills). In the digital cases, all part-tasks are performed within the whole-task context so that after finishing the case the student completed the whole-task.
It is important to realize that to acquire a mastery level in performing the complex cognitive skills described above, more whole task practice than provided by the digital cases is necessary. During this whole task practice, the student needs to acquire skills in performing all constituent cognitive skills of which the complex cognitive skills consist within the whole task context even when the whole task is not explicitly decomposed into its subsequent part tasks as is done in the digital cases. Therefore, after following the course of which the digital cases are part of, students are competent to participate in research projects (for example during their MSc thesis).

Timing of information presentation

After defining the learning (whole and part-) tasks, for each (part-) task the information (knowledge or skills) a student needs to possess to perform that task was identified. To decide on the moment when this information should be presented to the student, an important guideline used is "use Just-In-Time information presentation" (guideline 3). Shortly, Just-In-Time information presentation means providing the student with the necessary information needed at that moment for performing a task (11-13). According to van Merrienboer and Kester two information types can be distinguished, which are supportive and procedural information. They state that information supportive to the learning task is best presented before practicing the task and procedural information during practicing the learning task. Supportive information usually has a high-intrinsic complexity and is required to master non-recurrent aspects of the learning task. Procedural information usually is information with low intrinsic complexity and is required to master recurrent aspects of the learning task. After instruction and

practice, students ideally will be able to perform these recurrent (part-) tasks automatically.
Besides this distinction between two types of information, another distinction is relevant for the development of the nutrigenomics learning material. This is the distinction between information about genetics, nutrition, physiology, endocrinology, molecular biology etc. for which it can be reasonably expected that a large part (> 1/3) of the target group already acquired the knowledge (which makes this information redundant) and information that will be new to almost every student in the target audience. From now on, the former category of information is called "formally redundant" because ideally the student already possesses the related prerequisite knowledge. This type of information is also made available during the learning task (like the procedural information). Table 2 summarizes for case 1 and 2 the learning (part-) tasks together with some examples of supportive and procedural information and an example of "formally redundant" information.

Choosing human-computer interactions

Active learning is necessary for the understanding, acquisition and retention of knowledge (14). Furthermore, practice is believed to strengthen understanding (15). Therefore, human-computer interactions (i.e. interactive exercises) were implemented for the learning (part-) tasks to promote active learning (guideline 4). In addition, interactions were implemented to help the student comprehend the high-intrinsic complex information identified as supportive to the learning (part-) tasks. Several additional guidelines were developed for the design of human-computer interactions:

Guideline: Start each case with an interaction that aims at gaining the attention of the student

Several interactions are suitable for this purpose. For example, in the first case, the student had to visit some companies on the Internet, that claim to give a "personalized diet" advice. This makes the student curious to find out whether this is scientifically valid. Case 2 starts with a short news video clip in which the problem of obesity is presented.

Guideline: To assist the student in studying information supportive for the learning (part) tasks, use interactions that contain a low degree of freedom (see Figure 1) and which can be completed within a few minutes

In this way, these interactions do not involve the student in complex problem solving activities but trigger students to acquire knowledge by active studying the information. As a result, studying the supportive information does not distract the student's attention from the learning tasks that need to be completed in the cases, but prepares the student to successfully apply this supportive information during the learning tasks.

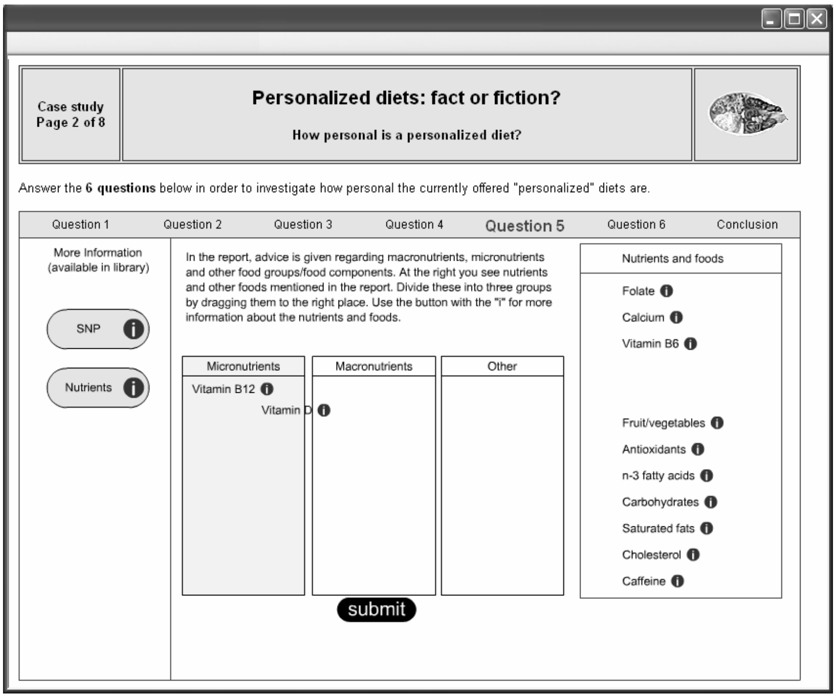

Figure 1a: Interaction type for supportive information.

a) Drag and drop interaction to acquire information about micro and macronutrients for which a diet advice is given. This information is supportive for the learning part-task "find out whether the personalized diet offered is really personal?" (case 1).

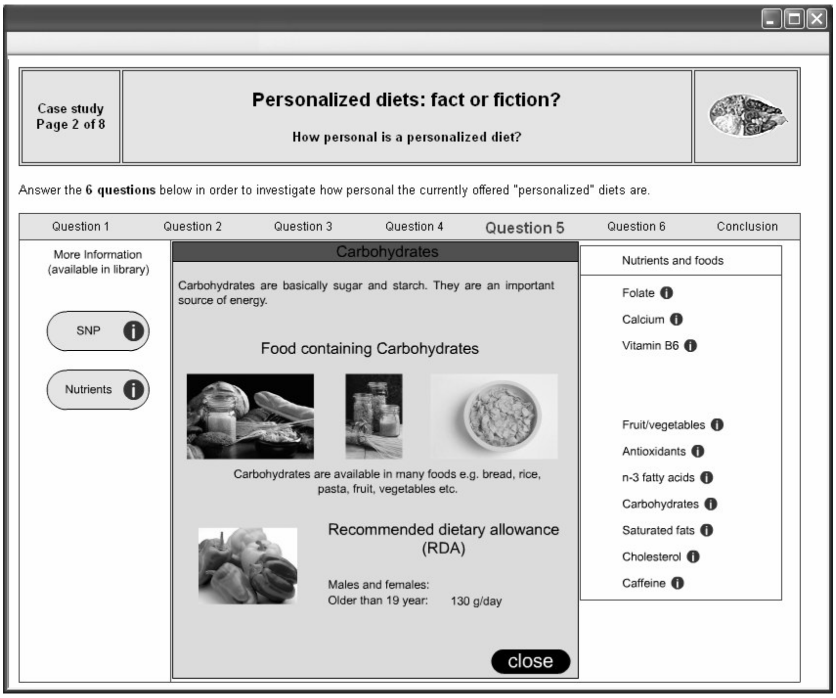

Figure 1b (continued): Interaction type for supportive information.
b) Information of specific nutrients is provided Just-in-Time to the student while performing the interaction of figure 1a.

Guideline: For the learning (part-) tasks, use interactions with a high degree of freedom for the student

Performing the learning (part-) task requires that the student uses the supportive information already studied to draw a conclusion, take a decision or discuss a statement. Providing an interaction with a high degree of freedom triggers the student to take time to perform the task and to combine the information already studied. A suitable interaction is for example a free format question or an interaction in which the student can choose from a large number (> 25) of options (Figure 2).

Guideline: Use the characteristics of the information to choose a suitable interaction type.

For example, a drag and drop interaction format can be used for information that consists of several items/concepts/examples etc that are grouped in one or more categories (figure 2). A “slider” interaction format can be used to help the student find out how changing the position, size or magnitude of a certain component influences a certain system or other components. Multiple answer or multiple-choice interactions could be used to confront the student with common misconceptions.

Choosing forms of information presentation

For the procedural information, no human-computer interactions are implemented because it is information with a low intrinsic complexity and practicing with this information automatically occurs during performing the learning (part-) tasks. Also for the 'formally redundant' information (for which it can be reasonably expected that a large part of the target group does not need this information) no human-computer interactions types are implemented. This information is presented during the learning task in small parts (with minimal intrinsic complexity) which take only a few minutes to study. After that, the student can immediately practice with this information by applying it to the learning task (see Figure 1b).

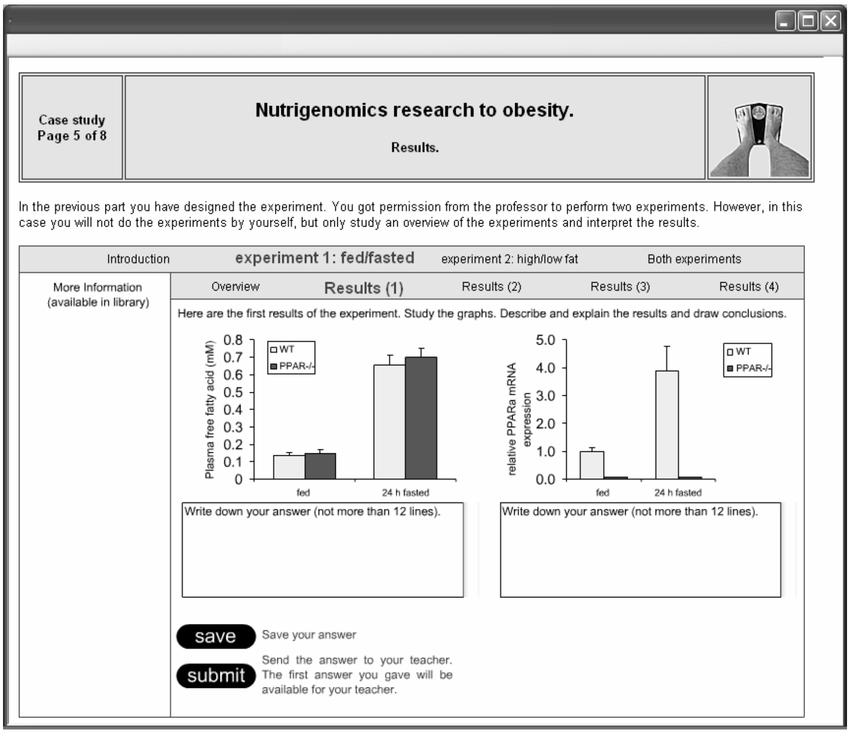

Figure 2a: Interaction type to perform a part-task.

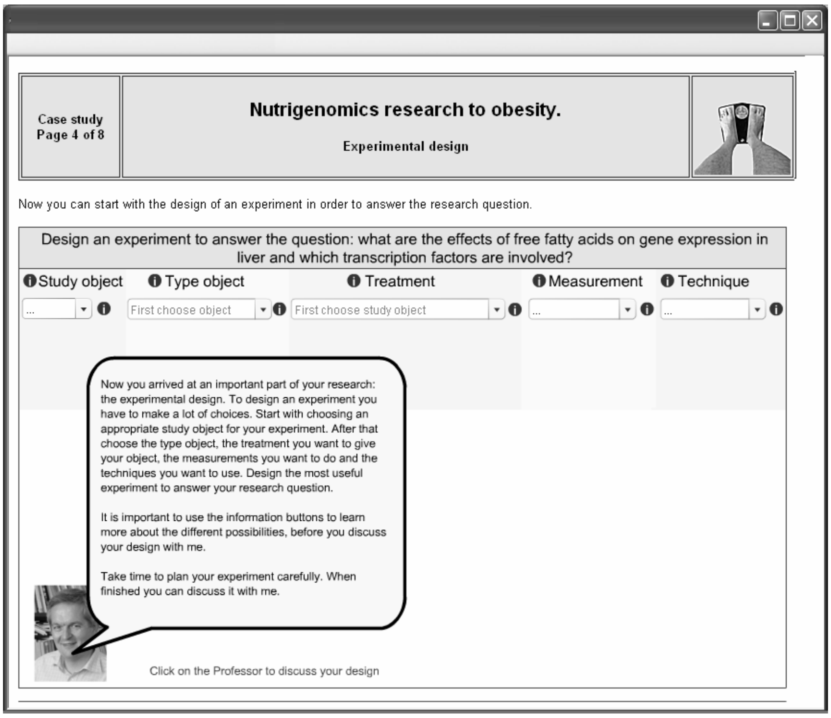

Figure 2b (continued): Interaction type to perform a part-task.
a) Interaction type to perform the part-task "design an experiment" (case 2). In this interaction type the student can design an experiment by choosing from more than 100 possible combinations of study object, treatments, measurements etc. b) Free format question to perform the learning part-task "interpret the results from your experiment" (case 2)

For the presentation of information, an important guideline is to visualize important concepts when possible (guideline 5). This guideline is especially important for the development of digital learning material. Using digital learning material makes it possible to use visuals (e.g. interactive diagrams, animations and video clips), which are more elaborate than figures in textbooks (16). Mayer states: "the promise of multimedia learning is that students can learn more deeply from well-designed multimedia messages consisting of words and pictures than from more traditional modes of communication involving words alone" (16). Furthermore, Larkin (17) and Sweller (15) suggest that, when well-designed images or diagrams accompany text, understanding and retention of knowledge will generally improve. Figure 3 gives an example of an animation used in the learning material.

The human-computer interactions, the visuals and animations are developed in Macromedia© Flash MX professional.

Assumption for the use of the learning material

From a design-oriented perspective, the environment in which the digital learning material functions consists of the educational setting in which the learning material will be used (e.g. the course in which the learning material is used, time scheduled to study the learning material etc.), the students who use the learning material (e.g. their prior knowledge, their learning processes, their motivation to study the learning material, their computer skills etc) and the technical facilities that enable the use of the learning material (e.g. the computer on which the learning material is used). To design learning material that is suitable for use in different environments, the design of the learning material needs to be based on a set of assumptions about its environment that is both minimal in terms of numbers as well as in terms of scope and impact.

Regarding the educational setting, few specific assumptions are made. This makes it possible to use the learning material in several different educational settings. For example the learning material could be used in a course in which the student follows lectures, laboratory assignments etc, or the learning material could be used as (part of) an e-learning course. In addition, individuals could use the learning material, outside the context of a specific course, to refresh their knowledge or acquire new knowledge. The most important assumptions about the students using the learning material have been described in the introduction. Most important, the target group may be heterogeneous with respect to their background and prior knowledge. Some assumptions are made about the technical facilities that enable the use of the learning material (e.g. the technical specifications of the computers and software). However, it is beyond the scope of this paper to describe all these assumptions in detail.

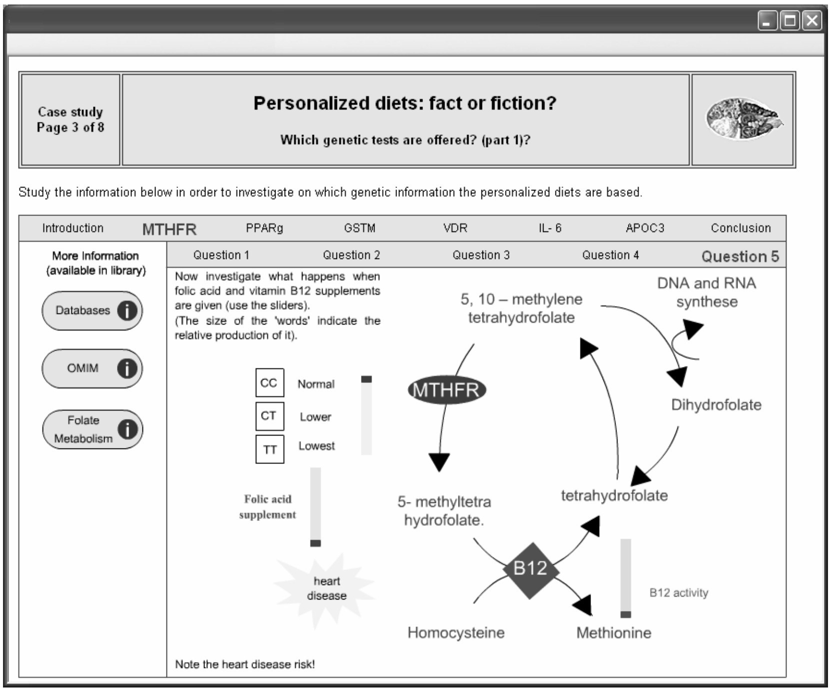

Figure 3: Example of information presented by means of a visual with a slider interaction type.

Evaluation of the learning material.

For the evaluation of the learning material, three types of evaluations have been applied: (a) an evaluation in which students, within a certain educational setting, evaluated the learning material, (b) an evaluation based on the exam results of student and, (c) an evaluation in which one or more (independent) experts in nutrigenomics or related fields evaluated the learning material. The purpose of these evaluations is to test whether the design satisfies (specific) requirements. Besides this, the evaluations may provide arguments to adjust the learning material.

For the first evaluation of the learning material, all three evaluation types were applied: During a 8-week introductory course to nutrigenomics (6 credits in the “European Credit Transfer System (ECTS)”)) students evaluated the learning material. Usually, at Wageningen University, students’ perception of the quality of courses, course material and teachers is assessed with standard evaluation forms using agree-disagree questions on a five-point Likert scale. The digital learning material was evaluated using similar evaluation forms. In addition, exam results of students were analyzed to get an indication whether the learning goals were reached. As part of this first evaluation an independent nutrigenomics expert reviewed the material, gave extensive comments and completed an evaluation form with agree-disagree questions on a five-point Likert scale. After this first evaluation, some limited adjustments to the learning material were done as recommended by the expert.

The second evaluation was performed in the same course, one year after the first evaluation. Again, students evaluated the learning material and exam results were analyzed. In connection to this second evaluation, three experts from several universities and institutes collaborating in the "European Nutrigenomics Organization" (NuGO) evaluated the learning material. Two experts filled in an evaluation form consisting of agree-disagree questions on a five-point Likert scale. The third expert just gave his general opinion about the learning material. This evaluation served two purposes. It was considered to be a formal evaluation of the learning material but also served to investigate whether the learning material would be useful as part of the nutrigenomics e-learning courses which NuGO intends to develop.

Results and Discussion

The first evaluation with students was performed during the introductory course in nutrigenomics. Students were from the master in Nutrition and Health, from the master in biotechnology, from the bachelor in biotechnology, from the bachelor in nutrition and health and from outside Wageningen, following an exchange program (22 students in total). It took students 8 - 12 hours to study each case once. Most students studied the learning material again, at home, in preparation to the exam. To study each case in depth took 16-24 hours (≈ 0.75 - 1 credit in the ECTS). Besides the digital learning material, the course contains lectures related to other nutrigenomics topics and a small laboratory part. Students studied the digital learning material in scheduled computer rooms. Table 3 gives an overview of the evaluation results. The table shows that the students enjoyed studying the cases and perceived to have learned much from it. They rated the cases with an overall score of 4.0 and 4.2 respectively. Furthermore, all the requirements were fulfilled. The fact that some students disagreed that the case links up well with what they already know, but agreed that they learned a lot from the cases and that the exercise in the cases were clear and understandable, indicates that the learning material was suitable for a target group heterogeneous with respect to prior knowledge.

Table 3: Results of evaluation in an educational setting

		First evaluation (n = 22)		Second evaluation (n = 15)	
no	Requirement	Case 1	Case 2	Case 1	Case 2
	Mean (% of students with a score of 6 or less)				
r1a	Exam results (10 point scale)	8.3 (10)	7.5 (38)	6.8 (32)	6.1 (47)
	Mean (% of students with a score of 4 or 5)				
r1b	I learned a lot from this case.	4.2 (91)	4.2 (95)	4.0 (67)	4.0 (75)
r1c	This case presents me with a clear example of				
	- nutrigenomics (case 1).	4.5 (100)		4.1 (83)	
	- a nutrigenomics experiment (case 2).		4.6 (95)		3.9 (83)
r2	The questions and activities raised my motivation to study.	-	-	3.8 (58)	3.9 (75)
r3	The exercises in this case have been clearly formulated.	4.4 (100)	4.5 (100)	4.0 (92)	3.9 (75)
	The feedback given on my answers was clear.	4.2. (91)	4.5 (91)	3.8 (58)	4.0 (83)
	The case links up well with what I already know.	3.6 (59)	3.8 (68)	3.6 (50)	3.3 (42)
r4	It is good that the questions and activities forced me to become an active learner.	-	-	4.0 (67)	4.1 (83)
r5	The visual aspects in this case helped me to understand important concepts.	-	-	4.4 (83)	4.0 (82)
r6	I enjoyed studying this case.	4.0 (68)	3.9 (77)	3.9 (58)	4.1 (75)
r7	Overall rating of the case (1 = poor – 5 = excellent).	4.0 (90)	4.2 (95)	3.7 (67)	4.1 (92)

Note that requirement r2, r4 and r5 are only evaluated during the second evaluation.

During this first evaluation, exam results of the students were analyzed. The exam consisted of 12 essay questions, of which approximately 25% of the questions were completely based on the learning goals, objectives and topics of the digital cases. The other questions assessed if students did acquire the supportive information presented in the learning material and if they achieved the learning objectives of the lectures and the laboratory part of the course. Table 3 shows that students performed well enough on the questions about the cases. Analysis of the answers

of the students on the other questions showed that the students did sufficiently acquire the supportive information (average score on the exam was 7.0 on a ten-point scale).
During this first evaluation, also an independent expert evaluated the learning material. Table 4 summarized the results of the expert evaluations. In general, the expert confirmed that the scientific information was sufficient and the educational approach was adequate. Based on this first evaluation, typological and technical errors in the learning material were corrected and some small adaptations were made, such as rephrasing of textual information, addition of information and making some small changes in structure and timing of presented information.
This adapted version of the learning material was evaluated during a second evaluation that took place in the same course as the first evaluation did, one year later. 19 Students did follow this course, of which 15 completed the evaluation form. Again, from this evaluation it appears that most design requirements were fulfilled, although the students scored some evaluation questions slightly lower and had a lower examination score than students did during the first evaluation (see Table 3). One explanation could be that, this time, most student encountered a technical problem (related to saving of their answers) while studying the learning material. The technical problem was solved during the second half of the course, however it is reasonable to expect that some students became frustrated because they did lose (some of) their answers they submitted and consequently spent less time in studying the learning material. In addition, although both evaluations were conducted in the same course in two subsequent years, the evaluations are not completely comparable. For example, the courses differ slightly with regard to the content of lectures given during the course, the team of instructors that was involved in the course and the time of the year in which the courses were scheduled. Furthermore, compared with the first evaluation, during the second evaluation relatively more students were from the master in Nutrition and Health and less from the master in Molecular Biology or Biotechnology, therefore it is reasonable to expect that the students differ with respect to their prior knowledge. Because both evaluations with students were not completely comparable with respect to the educational setting, technical facilities and student characteristics, the evaluation results are in line with the hypothesis that the material is suitable for use in different environments and for heterogeneous target groups.

In addition to this second evaluation, three independent experts evaluated the learning material (Table 4). Two experts filled in an evaluation form consisting of agree-disagree questions and one expert only gave a general opinion about the learning material. In general, these experts stated that the scientific information, educational approach, screen layout, text, colors, navigational aspects, pictures and animation were adequate (requirement r5b, r9, r10).

Table 4: results of expert evaluation.

no	Requirements	Expert 1	Expert 2	Expert 3
		Rating all cases	**Rating case1/case2**	
r1d	Rating of the scientific quality of the learning material	5	4/4	4/3
r4d	Rating of the screen layout, colors, pictures etc	3	4	5
r8	Rating of the pedagogical approach	4	4/5	3/5
r9	Rating of the navigational aspects	3	4/4	5/3
r10	Rating of the texts	3	4/5	5/5

Final remarks

The main challenges for the design of digital learning material that introduces students to the field of nutrigenomics was the formulation of learning goals and objectives, the identification of topics and the implementation of helpful learning tasks. An other challenge was to formulate new guidelines (in addition to guidelines described previously (5, 6)), derived from theories on cognitive science and instructional design, articulating the identification of supportive and procedural information for learning tasks, the selection of interaction types and the timing of information presentation by means of visuals and animations using different forms of Just-In-Time information presentation. It has been shown that these guidelines can be applied in order to develop learning material suitable for heterogeneous target groups. Further research has to be done to make clear whether these guidelines could be satisfactorily applied to the development of learning material in other scientific content areas, which differ more or less from the field of nutrigenomics.

From evaluation of the learning material during an introductory course to nutrigenomics, it became clear that the learning material was suitable for a target group that was heterogeneous with respect to their prior knowledge in nutrition, molecular biology, genetics and physiology. Gathering empirical evidence for the hypothesis that the material satisfies the design requirements in other educational settings and with other groups in the target population, which are defined by the assumptions listed above, still has to be done. From the evaluation with experts from NuGO it became clear that some of them agreed that the learning material would be suitable for their BSc, MSc or PhD students who require an introduction to nutrigenomics. Therefore, a first attempt to use the learning material within other educational settings is started by NuGO. The learning material is used as one of their e-learning modules. The first experiences are promising, but an extended evaluation has to be conducted to give more information about the usefulness of the learning material as e-learning module by an audience that will be more heterogeneous than the student population that used the learning material so far.

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CHAPTER 5

Design and development of digital learning material for applied data analysis

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Submitted

Abstract

Digital learning material was developed to help students acquire the necessary skills for the preparation and implementation of a data analysis protocol. The learning material focused on the relation between the main study types in human nutrition research and the appropriate data analysis methods. During the design process of the digital learning material, a satisfactory match between guidelines derived from theories on learning and instruction, specific learning objectives, and the possibilities of digital learning material was obtained. Evaluation of the learning material in an academic educational context indicated that students appreciated the learning material and achieved the learning objectives.

Introduction

The Nutrition and Health curriculum of Wageningen University includes several courses focusing on the correct use of statistical methods and techniques. In these courses, several methods and techniques are explained and used by students in the context of Nutrition and Health Research. In general, students who finish the courses can correctly apply a statistical method when asked to do so. However, even with this knowledge, they are still unable to identify appropriate statistical analysis methods for the analysis of their research projects, for example. This shortcoming revealed the need to focus on the close relationship between the main experimental and observational study types in human nutrition and health research and the appropriate method of data analysis. Therefore, digital learning material was developed to support students in achieving the following learning objectives: (a) matching specific statistical analysis methods with study types in human nutrition research, (b) developing a data analysis protocol, and (c) analyzing and interpreting the results.

The design of the learning material requires a satisfactory match between the characteristics of the learning material's core content, principles derived from theories on learning and instruction, and the possibilities of digital learning material. In putting together the learning materials, the first design challenge was to articulate detailed learning objectives. The next challenge was to articulate design principles derived from theories on learning and instruction that could guide the design process. During previous design oriented research projects, digital learning material for various disciplines was developed and the following guidelines for the design of digital learning material were identified (1-5):

1. Develop learning material that aims to motivate the student to study.
2. Prevent cognitive overload.
3. Promote active learning.
4. Visualize important concepts when possible.

See Box 1 for an extended explanation of these guidelines.

Related to these guidelines, two design challenges presented themselves: could the above principles guide the design of digital learning material for Applied Data Analysis and could design patterns be developed using these principles? Once design patterns were developed, it facilitated the production of several interactive cases with a similar structure, within the allocated budget. This resulted in learning material that consists of 10 cases, each focusing on a specific study type. Taken together, these cases cover study types and statistical analysis methods often used in Human Nutrition and Health Research. For the remainder of the paper, the phrase 'learning material for Applied Data Analysis' refers to this learning material.

Box 1: Guidelines for the development of digital learning material.

Guideline 1: Develop learning material which aims at motivating the student to study.
In general, motivation is essential for learning (6, 7). According to the ARCS model of Keller (8), four factors are essential to motivate students: Instruction should capture the Attention of the student, it should be perceived as Relevant, and it should induce Confidence and Satisfaction.

Guideline 2: Prevent cognitive overload
According to the cognitive load theory, an individual's cognitive capacity is limited and he can only process a certain amount of information at a certain time (9-11).
A principle that can be used to avoid unnecessary cognitive load and to reduce the risk of cognitive overload is Just-in-Time (JIT) information presentation. Van Merrienboer and Kester argue that learners need two types of information to perform a complex learning task: supportive and procedural information (12-15). They state that different principles of JIT information presentation can be used for these two types of information. Supportive information is information that teachers typically call 'the theory' and which is often presented in study books and lectures. This information is required to master non-recurrent aspects of the learning task and is highly specific for each task. Supportive information has to be presented before the learning task. Procedural information is information that provides the learners with step-by-step knowledge that is needed to perform recurrent aspects of learning tasks. Recurrent aspects of tasks can be performed in almost the same way for all tasks and will be performed automatically by experts. Procedural information has to be presented during the learning task.
Other principles to avoid unnecessary load are providing part-task practice (12) and excluding information from the learning material that is not directly relevant to the learning tasks.

Guideline 3: Promote active learning.
Active learning is necessary for understanding, acquiring and retaining knowledge (16). Therefore, it is important to develop learning material (or use educational activities) that stimulates the student to be actively engaged in studying.

Guideline 4: Visualize important concepts when possible.
It is suggested that "the promise of multimedia learning is that students can learn more deeply from well-designed multimedia messages consisting of words and pictures than from more traditional modes of communication involving words alone" (17). Digital learning material, in particular, provides ample opportunities to visualize important concepts, for example, by using animations, interactive graphs or pictures (18).

This paper illustrates how the abovementioned challenges were approached by justifying important design decisions and describing the outcomes of the design process. The main outcomes are (a) further articulation and explanation of the design guidelines in relation to the core content of Applied Data Analysis and (b) a detailed specification of the learning objectives, (c) the design patterns and (d) the final learning material. Although the main focus of this paper is the justification of the design process, an evaluation of the learning material in an academic setting is also given.

Design assumptions

Before starting the actual design process, design assumptions were made explicit regarding the educational setting in which the learning material would be used (e.g. the course and scheduled time), the students who would use the learning material (e.g. their prior knowledge), and the available technical facilities.

Although the formative evaluation of the learning material was intended to be carried out in a predefined educational setting, the design of the learning material was based on very few assumptions about the educational setting. This was done, so that the material could be easily used in different settings. For example, the learning material could be either part of a course in which the students attend lectures, read textbooks, and collaborate in group discussions, or the material could be used independent of a specific course, e.g. for brushing-up knowledge or for focusing on data analysis of a specific study type. This latter requires that each case be a self-contained learning unit.

A few assumptions were made regarding the students' prior knowledge. For example, it was assumed that students knew the purpose of statistical testing and the related terminology such as confidence interval and p-value. It was also assumed that students had experience with using a statistical analysis package such as SPSS or SAS for calculating means, standard errors, confidence intervals, performing statistical tests and so on. Some specific assumptions were also made regarding the technical facilities. However, an extended description of these assumptions falls outside the scope of this paper.

The design process

The learning material was designed by a team of scientific staff, lecturers and researchers experienced in data analysis for human nutrition research together with an instructional designer with pedagogical content knowledge and experienced in designing activating digital learning materials. During the development of the learning material (in Macromedia Flash MX 2004) a flash programmer was involved. The design process consisted of several sub-processes (see Figure 1 for an overview). In the following paragraphs the guidelines which played a role in each sub process and the outcomes of each sub process are described.

Learning Task Analysis

The purpose of the learning task analysis was to obtain a match between the learning objectives and the activities included in the learning material. Learning objectives describe what the student should know or should be able to do after studying the learning material. To determine exactly what students need to learn, it is necessary to separate the skills and knowledge the student need to obtain into their constituent skills.

Guidelines

An extended learning task analysis needs to aim at providing information that can be used to develop learning material in which unnecessary cognitive load is avoided and the risk of cognitive overload is reduced. Learning to master the complex cognitive skill of Applied Data Analysis brings with it a high risk of cognitive overload for students because they have to consider a large amount of information and knowledge at once (e.g. the nature of the data, study type, outcome measure, assumptions underlying specific statistical analysis methods etc) in order to develop a data analysis protocol. Students' cognitive load can be reduced if they train the constituent parts of the complex skill one-by-one using part-task practice. This allows students to practice with and process reasonable amounts of information before putting the complex whole back together. If part-task practice is not done, students run the risk of cognitive overload (12, 15). To develop part-task practice, the complex skill first needs to be broken down into its sub skills during the process of learning task analysis.

Theories of learning and instruction (see Box 1)

Core content 'Applied Data Analysis' (see Table 1)

Possibilities of digital learning material (see Box 1)

The design process

Learning task analysis

Purpose:
- to identify learning objectives and learning tasks
- to provide output for the use of cognitive load reducing principles during the design of task practice and information presentation
- to identify the learning objective for which task practice has to be developed

Guidelines:
Prevent cognitive overload, promote active learning

Outcomes (see Figure 2):
1. List of learning objectives and tasks
2. Identification of supportive information for learning tasks and procedural information
3. Identification of students' prior knowledge

Identification of contexts for the cases

Purpose:
- to provide an authentic context in which the core content for Applied Data Analysis can be studied
- to use contexts that will be perceived as relevant and which will gain student attention

Guideline:
Motivate the student.

Outcomes (see Table 1, fifth column):
1. List of specific contexts
2. Further specification of supportive and procedural information

Design of task practice

Purpose:
- to design opportunities for part-task practice to ensure that the student acquires all skills related to the learning objectives
- to provide part-task practice in a whole task context to help students integrate all skills in the whole task
- to design practice opportunities that enhance student confidence and satisfaction

Guidelines:
Promote active learning, motivate the student

Outcomes (see Figure 3 and 4):
Design patterns for part task practice in a whole task context

Design of information presentation

Purpose:
- to present information necessary for the learning task using presentation principles that aim at the prevention of cognitive overload
- to use different Just-in-Time information presentation principles for supportive and procedural information

Guidelines:
Prevent cognitive overload, visualize important concepts

Outcomes (see Figure 5):
Design patterns for the presentation of supportive and procedural information

Learning material for 'Applied Data Analysis'

Figure 1: Overview of the design process.
The design process was guided by principles from theories on learning and instruction (see Box 1), the core content 'Applied Data Analysis' (Table 1) and the possibilities of digital learning material. Four sub processes were distinguished. The text of the article illustrates the role of the guidelines in each process. The outcomes of the sub processes determined the final characteristics of the learning material.

Another principle that can be used to reduce the cognitive load of students working on learning tasks is the use of Just-in-Time (JIT) information presentation principles. Different principles of JIT information presentation have to be used for procedural and supportive information (see Box 1). Therefore, it is important to identify these two types of information for all skills and related learning tasks during the learning task analysis, so that JIT information presentation principles can be applied.

Outcomes (see Figure 2 and Table1)
The learning task analysis resulted in a specification of the learning objectives including a specification of the (sub) skills that the student has to acquire and the knowledge that a student has to use for performing the learning tasks. The analysis also resulted in a detailed description of the specific core content that will be covered by the learning material.

1. Learning objectives and learning tasks.
For the learning material for Applied Data Analysis, the main learning objectives are (a) to identify the appropriate data analysis method for study types relevant to human intervention trials and observational research and to prepare a protocol for data analysis, (b) to carry out the statistical analysis as described in the protocol and (c) to draw conclusions based on the results of the analysis. Thus, the complex cognitive skill that is involved in the learning material for Applied Data Analysis is 'the preparation and implementation of a protocol for the statistical analysis of study types often used in Human Nutrition Research'. Figure 2 shows a hierarchy in which the skills, described by the learning objectives, are broken down into their constituent parts. To develop a protocol for data analysis, the study type first needs to be identified. Then, an appropriate analysis method has to be selected, which requires that the student develops skills in identifying the appropriate outcome variable, exposure variable, outcome measure and effect measure. The next skill, 'performing the statistical analysis', mainly requires skills in using a statistical analysis software package. Finally, drawing conclusions from the statistical analysis requires knowledge on statistical concepts such as estimate, confidence interval, p-value and their interpretation in addition to knowledge on the aforementioned study characteristics. The learning task analysis also resulted in a

detailed overview of the core content that will be covered by the learning material (see Table 1, first four columns). While the learning objectives focus on the close relationship between the study type and data analysis method, it was decided during the learning task analysis which specific study types and data analysis methods would be covered by the learning material. Within Human Nutrition and Health Research, two research approaches can be distinguished: observational studies (e.g. case-control, cohort and cross-sectional studies) and intervention studies (e.g. cross-over and parallel arm intervention studies). The data types in this research area are continuous or categorical data (2 or more levels) for the exposure variable and continuous data, proportions or rates for the outcome variable.

2. Supportive and Procedural Information

The skills hierarchy in Figure 2 also provides two examples of supportive and procedural information that are needed to perform the learning task related to a specific skill. For example, identifying the appropriate analysis method is supported by information on characteristics of the study such as the study type. Information that is required for the tasks related to the use of a statistical software package is classified as procedural information because this information describes the steps needed to perform aspects of the learning task, which are almost the same for all data analysis problems.

3. Students' prior knowledge

It depends on the student's prior knowledge which information has to be presented in the learning material and for which information practice possibilities have to be provided. Assumptions about the students' prior knowledge are part of the design assumptions made explicit before starting the design process. For the learning material for Applied Data Analysis, it can be assumed that the students already possess most of the knowledge that should be gained by studying the supportive information.

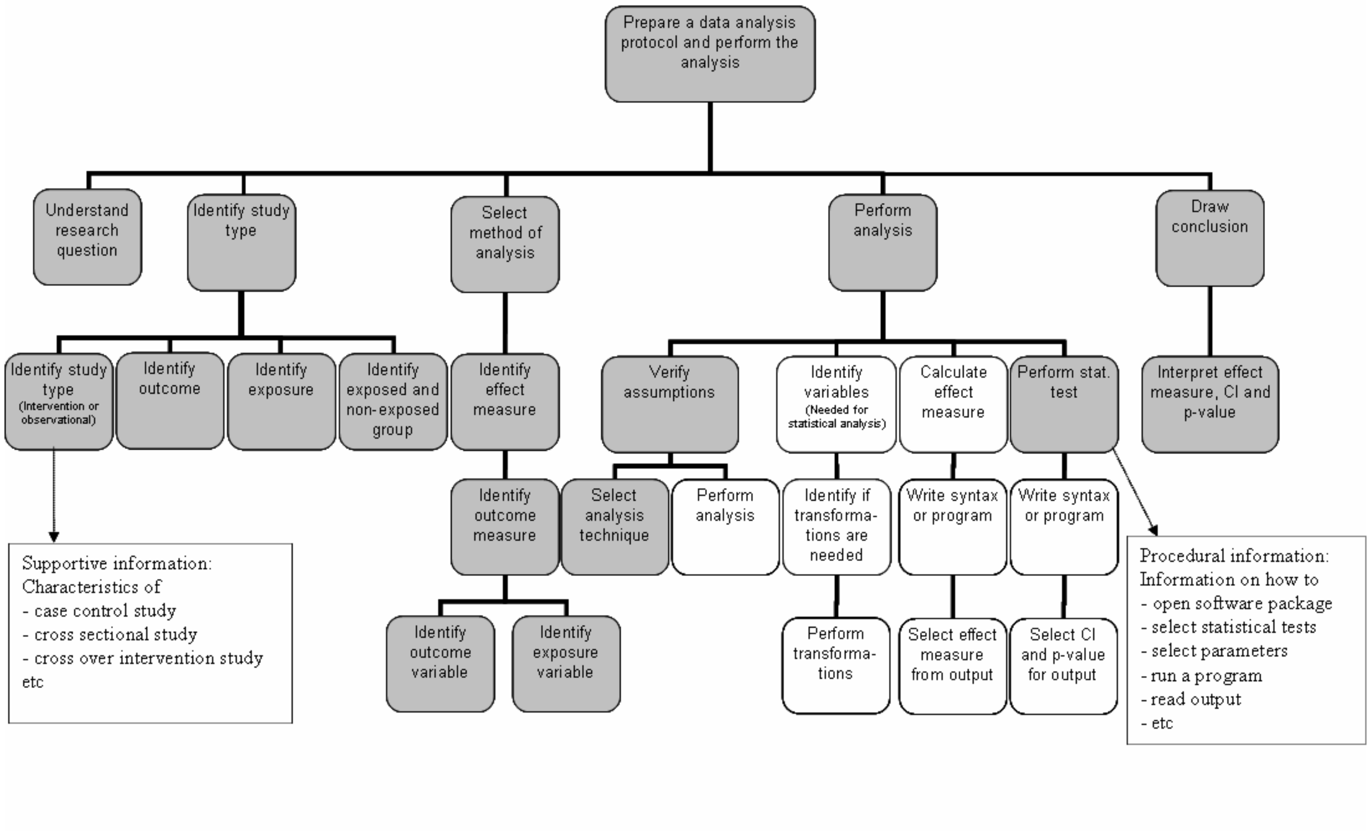


Figure 2: Hierarchy of skills described by the learning objectives.

Learning tasks are developed for all these skills. The white boxes describe skills or knowledge the student already obtained in other courses (assumed prior knowledge). As an example, information supportive of or procedural for the learning task is described for two of the objectives.

Identification of Contexts for the Cases

Guidelines

The learning task analysis indicates which core content will be covered by the cases. Next, it has to be decided which research examples could be used as context for the cases. This is not directly determined by the learning objectives and the core content of Applied Data Analysis. Many different research examples could be used to illustrate a specific 'study type – analysis method' combination. The first guideline for selecting appropriate examples as context for the cases is 'motivate the student'. The first two factors of the ARCS (Attention, Relevance, Confidence and Satisfaction) model of Keller (8) are most relevant in this respect (see Box 1). The Attention of the student can be gained by starting with a puzzling question or with an actual or controversial problem (see, for example, Figure 3). Furthermore, the student needs to perceive the context as Relevant. Realistic (real life) examples and contexts also have to be used because active construction of knowledge can be supported by providing meaningful, realistic and authentic learning contexts and activities that reflect the way knowledge is used in "real life" (19-21). Therefore, the studies used as examples in the learning material for Applied Data Analysis cover research questions in Human Nutrition and Health Research because students in Human Nutrition and Health are the primary target group for the learning material. Furthermore, authentic studies are used with enough information available (for example, on the research question and the purpose and relevance of the study) to provide a realistic and authentic learning context.

The guideline 'prevent cognitive overload' also plays a role while identifying appropriate contexts for the cases. Often, there is a tendency to include "nice-to-know" information in the learning material although this information does not contribute to the learning objectives, and it does not support the learning task. Including this unnecessary information increases cognitive load and could lead to a decreased learning capacity. For example, for the Applied Data Analysis learning material, information on the mathematical background of statistical methods is excluded from the learning material unless that information is essential for choosing the appropriate technique or for conducting the analysis. However, the guideline 'motivate the student' sometimes implies that information not essential for the learning objectives is included in the learning material, e.g. a puzzling question or information to focus the student's attention. To prevent cognitive overload, this information should be easily understandable and should not distract the student from the learning task.

Outcomes (see Table 1, fifth column)
In addition to the core content covered by the learning material, Table 1 lists the studies used as context for the cases. All studies explore important former or current research questions in Human Nutrition and Health Research (e.g. the relation between plant sterols and serum cholesterol). Furthermore, not only studies related to the intake of a specific nutrient (e.g. protein) or food (e.g. pineapple) and a certain disease (e.g. gallbladder cancer) or marker of disease risk (e.g. high serum cholesterol as a marker for heart disease risk) are chosen, studies related to nutrition behaviour (e.g. the effect of skipping breakfast or the effect of a lifestyle intervention) are also selected. Using a variety of studies aims at gaining the student's attention. This variety also helps students understand the relevance of the statistical analysis methods and the study types covered by the learning material because it becomes clear to them that these methods are relevant for a broad range of research topics.

Design of Task Practice

Guidelines
An important guideline for the design of the task practice is to actively engage the student in studying. The learning material provides possibilities to train each part-task to ensure that the student acquires all skills related to all part-task aspects of the learning task. In training the part-tasks, it is important that the part-task exercises are presented within the whole task context; otherwise, the student will train each sub skill but will not be able to integrate the sub skills to perform the whole tasks. Therefore, the cases have a format that helps students to recognize the relationship between all steps (part-tasks) needed for the development of a data analysis protocol and the statistical analysis (whole task).
Next, the guideline ‘motivate the student’ is important. Again, Keller's model was used (8). For the design of the task practice, it is especially important to develop exercises that give the student Confidence and Satisfaction. Consequently, each exercise is immediately followed by feedback that assesses the given answer or gives directions to find the right answer, so that each student in the end will be

able to find the right answer. Moreover, since each case has the same format and almost the same type of questions, the student will find the exercise quite satisfying because after a while he will be able to find the right answers without extensively using the feedback. This is the same with the supportive information for the learning tasks: after studying a few cases the student will be able to answer the questions using less of this JIT information. This will induce satisfaction and confidence because the student becomes convinced that he will be able to analyze a study by himself, for example, during his own research project. Because the supportive information is available for all cases, the cases can be studied independently and in a flexible order.

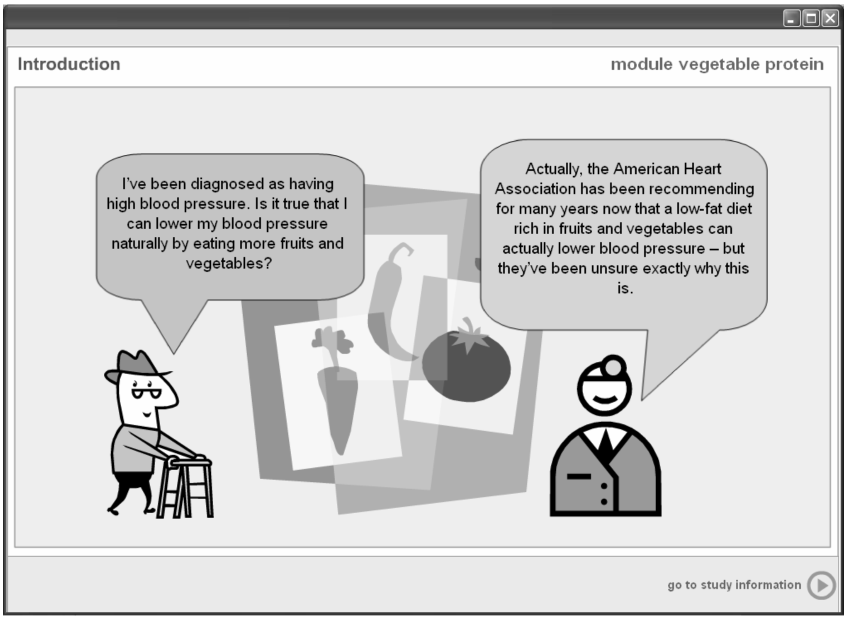
Outcomes (see Figure 4 and 5)

The main outcome of the part-task design is a design pattern and a set of exercises that conform to this pattern. A design pattern is a recurring pattern in configurations of components or basic operations that fits a certain type of problem or challenge. The knowledge of an expert designer mostly consists of many design patterns. The concept of the design pattern was first introduced by Alexander (22). During the last decade, the concept has received more attention in education (23).

The design pattern shown in Figure 4 illustrates how part-task practice can be provided within a whole task context. Figure 4 shows the main screen of a case. After a short introduction to the case topic, the student comes to this main screen. From this screen the student can access all the part-task exercises such as the exercises shown in Figure 5. After performing a part-task, the results are shown on the main screen (Figure 4b). In this way, the main screen provides the student with an overview of all important part-tasks and their results within the whole task context. At the same time, the main screen provides a template for a data analysis protocol. The use of this design pattern illustrates how a satisfactory match between principles derived from theories on learning and instruction, characteristics of the core content for Applied Data Analysis and possibilities of digital learning material was obtained: The design of the main screen enables part-task practice in a whole task context (educational principle), the design pattern is based on the learning objectives in Applied Data Analysis (characteristics of the core content) and can be reused in all cases (possibility of digital learning material).

Table 1: Core content and context of the cases.

Study type	Core content covered by the cases: Usual nature of the data – exposure	Usual nature of the data – outcome	Effect measure and Data analysis methods	Context of the cases studies
Intervention studies				
Parallel intervention study	Dichotomous	Continuous (normal distribution)	Mean difference Independent-samples test	N-3 fatty acids and heart rate (24)
Cross-over intervention study	Dichotomous	Continuous (normal distribution)	Mean difference Paired-samples t-test	Plant sterols and serum cholesterol (25)
Parallel intervention study	Dichotomous	Discrete (proportion)	Incidence proportion ratio Chi-square test	Lifestyle intervention and glucose tolerance (26)
Parallel intervention study	Dichotomous	Continuous (log normal distribution)	Mean difference Paired-samples t-test (including transformations)	Nutritional education and serum C-reactive protein (27)
Parallel intervention study	Dichotomous	Continuous (non-normal distribution)	Mean difference Mann-Whitney test (nonparametric)	Flaxseed and plasma enterolactone (28)
Parallel intervention study	Categorical > 2 levels	Continuous (normal distribution)	Mean difference One-way ANOVA (contrast or post hoc tests)	Betaine and homocysteine (29)
Observational studies				
Cross-sectional study	Continuous	Continuous (normal distribution)	Regression coefficient (simple) linear regression	Vegetable protein intake and blood pressure (30)
Prospective cohort study	Dichotomous	Continuous (rates)	Incidence rate ration Chi-square test	Mediterranean diet and mortality (31)
Cross-sectional study	Dichotomous	Discrete (proportion)	Prevalence ration Chi-square test	Skipping breakfast and obesity (unpublished data)
Case-control study	Dichotomous	Discrete (proportion)	Odds ration Chi-square test (logit)	Pineapple and gallbladder cancer (32)



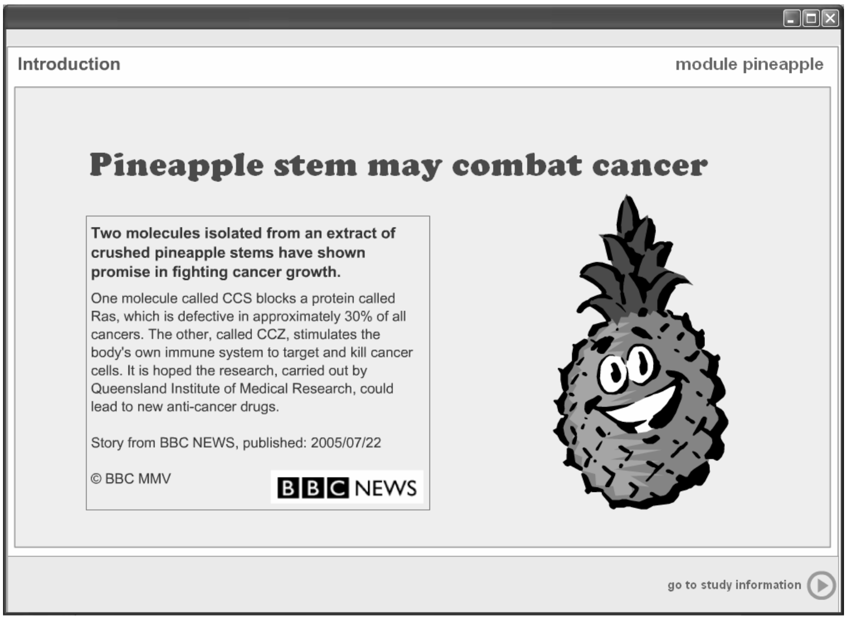
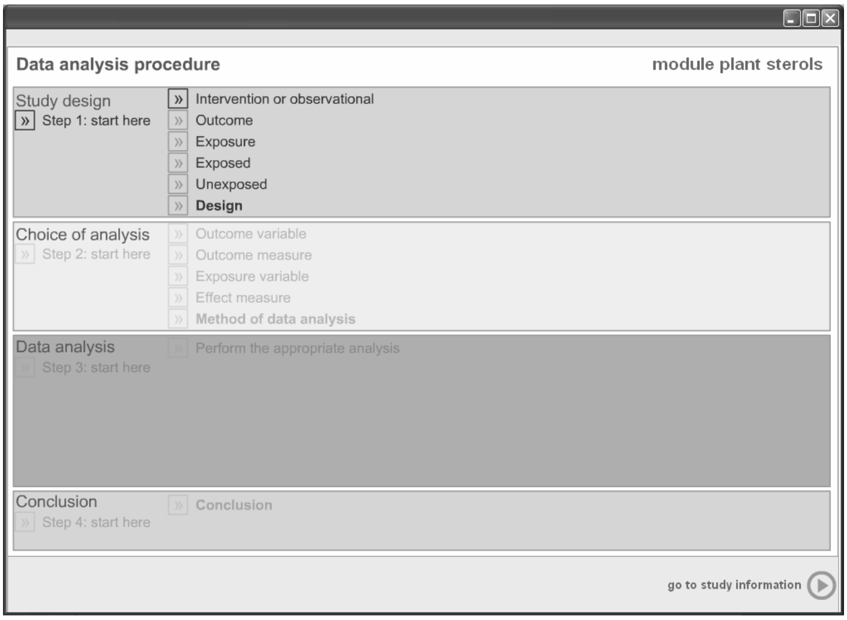


Figure 3: Contexts of the cases
(a): The introduction to the case 'vegetable proteins and blood pressure' starts with a puzzling question to arouse the student's interest. (b) The case 'pineapple and gallbladder cancer' is introduced by starting with an actual news story to show the relevance of the topic.



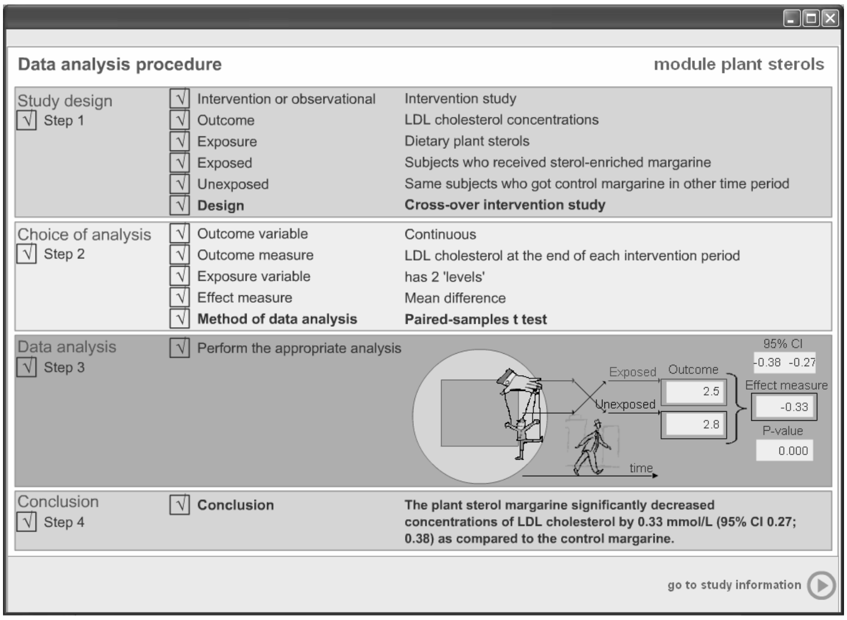
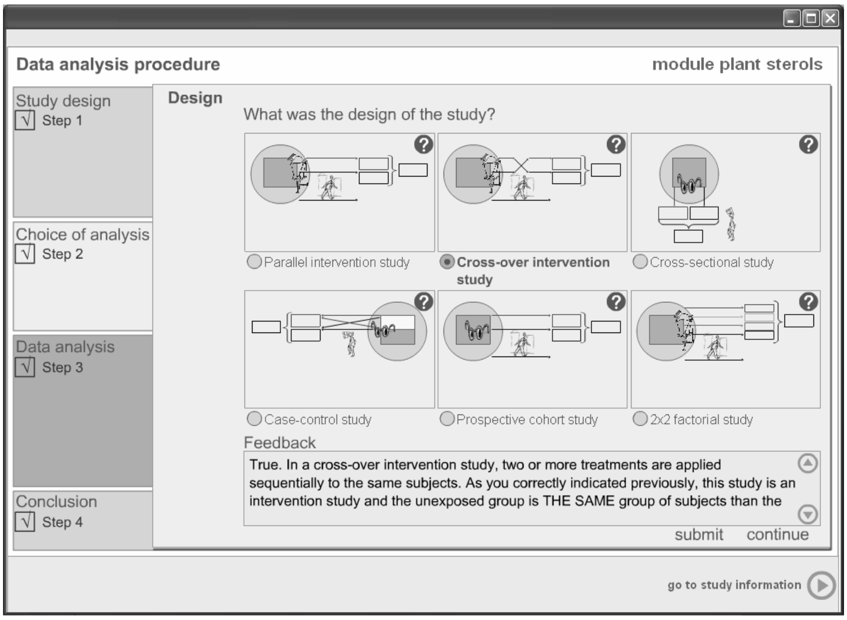


Figure 4: main screen

(a) When a student starts with a case, he can only answer the questions about “study type”. (b) After finishing the case, all answers are shown on the main screen. Results of the data analysis are shown in the second half of the main screen.



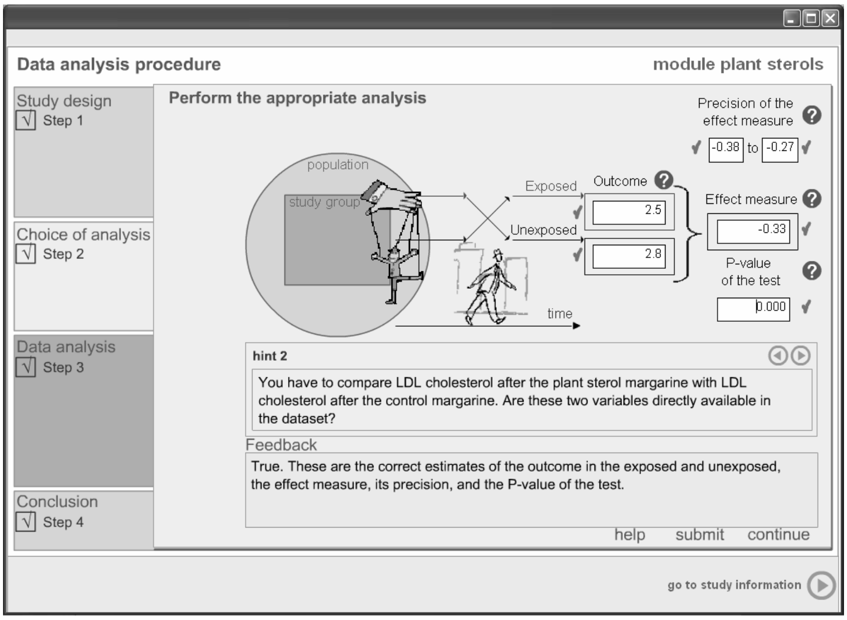


Figure 5: Part task practice

(a) Exercise for the objective "identify study type". (b) Exercise for the objective "perform analysis". Both exercises illustrate the combined presentation of supportive information and the learning task.

Design of Information Presentation

Guidelines

To reduce the risk of cognitive overload, it has been suggested to use JIT information presentation principles. Merrienboer and Kester (12-15) have suggested presenting supportive information prior to the learning task (see Box 1). Nevertheless, the supportive information is made available in the learning material for Applied Data Analysis during the learning task. Because it is assumed that the students already possesses most of the knowledge related to the supportive information, the main purpose of making this information available is to refresh students' prior knowledge.

Additionally, some of the supportive information on study type is woven into the learning task. According to the learning objectives, the supportive information on study type is closely related to the learning tasks. Therefore, it is assumed that the supportive information should not be separated from the learning tasks. Presenting the supportive information within the learning task helps the student discover the direct relevance of the supportive information for the learning task. In the next paragraph, two design patterns based on these arguments are presented.

Finally, following the guideline 'visualize important concepts when possible', it is important to make use of the possibilities of digital learning material during the design of information presentation.

Outcomes (Figure 5)

Two design patterns were developed for the design of information presentation. The first design pattern is related to the combined presentation of supportive information on the study types and the learning task 'perform the analyses'. Before choosing the appropriate method of analysis, the student has to recognize the study type using a short description of the study. Each study type is visualized in a scheme. In these schemes, the relation between study types and outcome measures are visualized (see Figure 5a). Once the student correctly identifies the study type, the visualized relation between study type and outcomes helps the student to identify outcome variables, outcome measure, effect measure and finally the method of data analysis. During the task 'perform the analysis', the same scheme is used to fill in both the outcome and the effect measure as well as other results of the data analysis. In this way, the study type is directly linked to the effect measure and method of data analysis, to help the student understand the close relationship between them.

Another design pattern used in almost every exercise pertains to the JIT presentation of supportive information during the learning task. Most exercises can only be completed when the student has knowledge on, for example, study types, statistical methods for data analysis or terms related to statistical testing. While it is assumed that the student has already acquired this knowledge in previous courses on epidemiology, research methodology or statistics, this information is also available during the exercises to refresh the student's prior knowledge. The student can request the information by clicking on the button with the question mark (see, for example, Figure 5, where information on study types can be requested). This is one principle of JIT information presentation: information is available at the moment the student needs it to complete the exercise. Also, procedural information is available during the learning tasks. For example, in Figure 5b the student can request hints that guide him in using a statistical package for data analysis, such as SPSS.

Formative evaluation

Methods

To get an initial idea of the learning material's usefulness, the material was evaluated in an educational setting. Formative evaluation of the learning material does not intend to provide a scientific evaluation of the design guidelines but is intended to identify shortcomings of the learning material and to measure which design requirements are met once the learning material is in use. The design requirements are presented in Table 2.

Formative evaluation of the learning material took place in the course Applied Data Analysis in Human Nutrition and Health Research, in which 57 students were enrolled. This course is taken by second-year bachelor's students of the Nutrition and Health curriculum and first-year master's students of the same curriculum who did not attend this course (or a similar one) during their bachelor's program. The students' prior knowledge was in line with the design assumptions. In the first half of the course, students studied the digital learning material. The second half of the course was reserved for other topics related to data analysis in human nutrition research (e.g. sample size calculations, confounding and energy adjustment). The digital cases were introduced with a short lecture, stating the

purpose and learning objectives for the cases. The cases were studied during scheduled computer practicals. Four hours were scheduled for each case. During these hours a supervisor was present to answer questions and to observe the students while they worked on the learning material. During the practicals the students were asked to report everything that was not clear.
To get an impression of the students' perception of the learning material, students were asked to complete an evaluation form consisting of agree-disagree questions on a five-point Likert scale. Table 2 lists the requirements and evaluation questions. In addition to this, the students' exam results were analyzed to evaluate whether the learning objectives had been met. The exam contained several questions for each of the learning part-tasks (see Box 2 for some examples). In total, the exam consisted of 40 multiple choice questions, of which 25 were directly related to the objectives of the digital learning material. The remaining 15 questions were related to other topics covered in the course as mentioned before. With respect to the exam questions, the design requirement that had to be fulfilled was that two-third of the students on average had to be able to answer correctly the exam questions related to each of the part learning tasks.

<u>Results</u>
The evaluation results indicated that the learning material fulfilled the design requirements (see Table 2). Eighty-six percent of the students completed the evaluation form. In their responses, 76% of them indicated that the learning material helped them to achieve the learning objectives while 80% indicated that they had learned a lot from the learning material. All students indicated that the learning material was clear and understandable. More than 80% of the students appreciated the activating elements and the visuals in the learning material. The learning material in total was rated with an average score of 4.1 on a 5-point scale.
Evaluation of the exam questions indicated that more than two-third of the students achieved the learning objectives. On average, 84% of the students were able to answer questions related to identifying study type properly, 72% could answer questions related to the identification of the appropriate effect measure, 74% could answer questions related to the selection of the appropriate method of analysis and 68% could answer questions related to the interpretation of the results of the analysis. Observing the students working on the learning material did not reveal serious shortcomings of the learning material. All students were able to

complete each case within 4 hours with hardly any additional support from the supervisors. Some students requested support from the supervisor while they were analyzing the data in SPSS because they had had less experience in analyzing data with SPSS than assumed.

Box 2: An example of an exam question.

First read this small fragment from an abstract published in a scientific paper
We compared the self-reported health status of 2467 participants in the "Dialysis Morbidity and Mortality Study Wave 2" by using body mass index (BMI; in kg/m2) to approximate body size and composition. BMI was categorized into 2 groups corresponding to World Health Organization criteria for underweight/normal-weight, and overweight/obese status.
The following 3 questions concern this abstract.

Question 1
What was the type of study described in this abstract?
a) Case control study
b) Cross over intervention study
c) Cross sectional study
d) Parallel intervention study

Question 2
What effect measure can be used to compare the outcome between the exposed and the unexposed in the study described in this abstract?
a) Incidence proportion ratio
b) Incidence rate ratio
c) Prevalence proportion
d) Prevalence ratio

Question 3
What is the basic method of data-analysis in the study described in this abstract?
a) Chi-square (or Fisher's exact) test
b) Correlation
c) Independent-samples t test
d) One-sample t test

Table 2: Design requirements and evaluation results

Requirement	Evaluation question (using agree-disagree questions on a five-point Likert scale)	Mean (% ≥ 4) (n = 49)
Students indicate that the learning material helped them to reach the learning goals.	I feel confident that I would be able to perform a simple data analysis on my own (e.g. during my thesis.)	4.1 (76)
	Studying 10 cases with a similar structure helped me to understand the general analysis strategy.	4.5 (94)
Students indicate that they learned a lot from the digital learning material.	I think I learned a lot from the cases.	4.2 (80)
	I think I learned a lot from analyzing data in SPSS because I was forced to think for myself.	4.0 (73)
Students indicate that the components that require them to become active learners motivate them to study.	The questions and activities raised my motivation to study.	3.9 (69)
Students indicate that the digital learning is material clear and understandable.	The exercises in the cases have been clearly formulated.	4.7 (100)
	The feedback given on my answers was clear.	4.2 (86)
	These cases link up well with what I already know.	4.2 (84)
	Analyzing the data in SPSS was too difficult.	2.0 (8)
	There were not enough hints available during the data analysis part.	2.2 (16)
Students indicate that the questions and activities in the digital learning material forced them to become an active learner.	It is good that the questions and activities forced me to become an active learner.	4.3 (84)
Students indicate that the visualization helped them to understand important concepts.	The visual aspects in the cases helped me to understand important concepts.	4.4 (86)
Students enjoyed the digital learning material.	I enjoyed studying the digital cases.	4.5 (90)
Students' overall judgment of the learning material is positive.	Overall rating of the cases.	4.1 (85)

Discussion

Activating digital learning material for Applied Data Analysis was designed, realized and implemented in education. The outcomes of the design process included (a) the articulation of design guidelines, (b) a detailed specification of the learning objectives, (c) design patterns, and (d) the learning material and its evaluation. The digital learning material was designed to assist the student in training (sub) skills related to the development of a protocol for data analysis in which the close interrelationship between study type and data analysis methods are considered.

It is important to realize that more whole task practice than that provided by the digital cases is necessary to master the whole complex cognitive skill. During this whole task practice, the student needs to acquire skills to perform the whole task, even when the task is not broken down into its constituent part-tasks as is done in the cases (12). Therefore, the students not only studied the digital cases during the course, but they also developed their own protocol for data analysis, which was not guided by specific digital learning material. This task mimics the situation a student will encounter during future research projects in their curriculum. Further research is necessary to investigate whether the described design guidelines and design patterns can be used to develop additional digital learning material aiming at the acquisition of the whole task or whether a further articulation of the design guidelines and the development of additional design patterns are necessary.

The development of several design patterns illustrates how the challenge to find a satisfactory match between guidelines derived from theories on learning and instruction, content specific learning objectives and the possibilities of digital learning material was approached. It is hypothesized that several of the design patterns could be reused or adapted to develop learning material with similar learning objectives. For example, the design pattern for the main screen of the cases could possibly be reused for the development of learning material that aims at acquiring skills in using more sophisticated methods for data analysis, such as multivariate analysis methods. Further research is also necessary to investigate the extent to which this design pattern needs to be adapted to specific learning objectives before it can be reused.

Evaluation of the learning material in use indicated that it fulfilled the design requirements. Although this formative evaluation was not intended to evaluate the design guidelines, it does give a first indication that following the guidelines leads to learning material that is appreciated by the students and that helps them achieve the intended learning objectives.

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CHAPTER 6

Interactive digital learning material on collating evidence from Human Nutrition research

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Abstract

Educational literature suggests that digital learning material provides opportunities to promote active learning, to present individualized feedback, and to reduce the risk of cognitive overload.

The aim of this study was to investigate the possibilities of digital learning material for academic Human Nutrition education. Therefore, the above described educational principles were further articulated to guide the design of the learning material. The material aims to assist students in obtaining insight into strengths and limitations of common approaches in Human Nutrition research (i.e. animal experiments, intervention studies and observational research) and the rationale and application of a wide range of methods often used for evaluating and collating scientific evidence from nutritional and biomedical research.

The learning material consists of two cases, one on alcohol intake and coronary heart disease and one on milk consumption and bone health. Each case contains various interactive and visual elements to promote active learning. The learning material was evaluated in two academic courses, a BSc course (26 students) and a MSc course (45 students). The interactive elements were rated on a five point scale with a 3.5 (BSc) and 4.2 (MSc) and the visual elements with a 3.9 (BSc) and 4.1 (MSc) (average over two cases). Exam results indicated that the different learning objectives were achieved by 65% to 88% of the students. This study illustrates how principles derived from theories on learning and instruction can be used to develop pedagogical sound, interactive and visual learning material for academic Human Nutrition Education.

Introduction

The science of Human Nutrition studies the relationship between food or nutrient intake and human health, from both a biological and social perspective. With respect to the biological dimension, literature usually distinguishes three or more conceptual levels or levels of organizational complexity, although the description of the levels and their boundaries are somewhat different (1-3):

1. Nutritional genomics and genetics at the cell, tissue or organ level.
2. Nutritional physiology at the individual or organism level.
3. Nutritional epidemiology at the level of the population and the society.

The curriculum 'Nutrition and Health' at Wageningen University is organized along these lines. BSc students should develop basic knowledge of the wide scope of the field of Human Nutrition and MSc students start with developing expertise in nutritional research on at least one of the three research levels which can be continued in a PhD program.

Each of the above-mentioned research levels is covered by separate mono-disciplinary courses. Consequently, students developed knowledge and skills related to each of the levels separately. Implicitly, it was assumed that if students were trained in applying concepts, theories and knowledge on each level separately, they would automatically develop insight into the wide scope of Human Nutrition and be able to combine these concepts in the process of evaluating scientific evidence for a proposed biological relation between a nutrient, food or food pattern, and a health outcome. Although the development of this insight was considered an important objective of the curriculum, it appeared that scientific staff doubted whether students indeed achieved it. This revealed the need to explicitly introduce this as a learning objective into the curriculum. Interactive digital learning material was developed for this purpose because the use of digital learning material provides more opportunities to promote active learning, to present individualized feedback and to reduce the risk of overloading student's cognitive capacity than traditional learning materials.

The main aim of this paper is to give a justification of the decisions taken during the design of the learning material. In addition we provide a short evaluation that aims to investigate whether the learning material satisfies preset criteria with respect to students' appreciation and achievement of the learning objectives.

Material and Methods

Design of the learning material

Learning objectives

The learning material was developed to assist students in obtaining insight into the characteristics, strengths and limitations of research approaches often used in Human Nutrition research. Three research approaches are distinguished: (a) Laboratory research using animal or cell line models, as characteristic approaches in nutritional genomics research, (b) Human intervention studies, as a characteristic approach of research at the individual level, (c) Observational research as a characteristic nutritional epidemiological approach.

To achieve this objective, the students should develop insight in the rationale and the application of a wide range of methods often used for evaluating and collating scientific evidence from nutritional and biomedical research (4). With this respect, the students should understand the role and limitations of the well-known 'Bradford Hill's Criteria for causation' (5) which focus on both biological and methodological aspects, of the hierarchical 'evidence pyramids' (6) which order study types according to the strength of evidence they could provide and of the more recent method proposed by the FDA (7) and the project to establish a Process for the Assessment of Scientific Support for Claims on Foods (PASSCLAIM) (8) which not only evaluates the appropriateness of the study type but also the quality of the study design, execution and analysis. Next the student should obtain insight in mechanistic orientated diagrams as the biomarker diagram that provides a flow chart of classes of biological markers for exposure, nutrient status and risk (9). Finally, the student should be aware of reviewing methods to summarize strength of scientific evidence like systematic reviews and meta-analysis. Together, the above mentioned methods were thought sufficient to assist the student in obtaining insight into the wide range of commonly used methods and the different methodological, biological and analytical issues which play a role within the process of evaluating and collating scientific evidence.

The learning material focuses on evaluating scientific evidence for a proposed biological relation and not on subsequent governmental and industrial policies. A solid understanding and insight in the above mentioned methods was considered a prerequisite for subsequent application in policy making, which is covered in other courses in the curriculum. Besides, the learning material does not cover the

social and behavioral dimensions of Human Nutrition, although this could be seen as an integral part of nutritional science (10, 11).
Table 1 further illustrates how students should demonstrate that they achieved the learning objectives within the exam of the courses in which the learning material was used.

Table 1: example of an exam question.

Below you find a small fragment of an article about fiber intake and colorectal cancer. In this article all three approaches are mentioned. Read this and answer the questions below.

Dietary Fiber and Colorectal Cancer: An Ongoing Saga
Adapted from John A Baron (35)

About the association of fiber intake and colorectal cancer this article stated:
"Animal studies have variably suggested that fiber has reduced risks, increased risks, or had no effect on experimental bowel cancer. Observational studies have found intake of dietary fiber to be either protective or to have no effect (….). Intervention trials (with adenoma* endpoints) have found either no effect or increased risks. (….)"
* adenomas (polyps in the colon) could become malignant and lead to colon cancer, however, not all adenomas will become malignant.

Give four explanations for these inconsistent findings. Use the directions given below.

1. Speculate if the endpoints used in each approach could explain the inconsistent findings.
2. Speculate if information bias and compliance could explain the inconsistent findings.
3. Speculate if confounding bias could explain the inconsistent findings.
4. Speculate if the amount of fiber intake (doses) differs between the approaches and if this could explain the inconsistent findings.

Imagine that one of your fellow students concludes:
'There is sufficient evidence that fiber intake increases the risk of colorectal cancer, because human intervention trials do show this, and randomized controlled trials are thought to provide strongest evidence for a proposed causal relation between an exposure (nutrient or food) and an outcome (disease or other health outcome).'

5. Do you agree with this conclusion? Explain your answer!

Assumptions on student's prior knowledge

The learning material does not intend to train students in research methodology for each of the research levels separately. Therefore, it is assumed that students have some prior knowledge on research methodology (e.g. the different study types, simple statistical analysis methods etc). The learning material has to be useful for student groups heterogeneous with respect to their areas of specialization and their depth of prior knowledge. Therefore, all information on methodology, physiology and metabolism which is essential to understand the learning material is provided within the material to refresh prior knowledge or to fill knowledge gaps if necessary.

Design guidelines

During previous projects, digital learning material was developed to assist students in obtaining knowledge or skills related to either nutritional genomics and genetics (12), nutritional epidemiology (13), and the behavioral dimensions of Human Nutrition (14). For the design of these materials, guidelines were formulated derived from theories on learning and instruction and the possibilities of information technology. The next section summarizes these guidelines as they were also used during the design of the learning material described in this paper.

Guideline 1: Aim to motivate the student to study

As attention and motivation of the student can be seen as the bottleneck in education (15, 16), this guideline was considered useful. According to the ARCS model of Keller (17), four factors are essential to motivate the students: Instruction should capture the Attention of the student, it should be perceived as Relevant, and it should induce Confidence and Satisfaction.

Guideline 2: Provide an authentic learning context

Learning is achieved by active construction of knowledge and can be supported by providing meaningful and authentic learning contexts and activities which reflect the way knowledge is used in "real life" (18-20). It was considered useful to provide authentic research examples to help the student understand the characteristics, strength and limitations of the research approaches. In addition, the student can only develop awareness of the importance and practical relevance of the process of evaluating and collating scientific evidence if this process is illustrated by authentic examples.

Guideline 3: Promote active learning.
Because active learning and practice is necessary for understanding, acquiring knowledge and retention of knowledge (21, 22), it was considered useful to develop learning material that stimulates the student to be actively engaged in studying.

Guideline 4: Visualize important concepts when possible.
Mayer claims that "the promise of multimedia learning is that students can learn more deeply from well-designed multimedia messages consisting of words and pictures than from more traditional modes of communication involving words alone" (23). Digital learning material provides ample opportunities to visualize important concepts, by using animations, interactive graphs and pictures (24).

Guideline 5: Avoid unnecessary cognitive load and prevent cognitive overload.
According to the cognitive load theory an individual's cognitive capacity is limited. There is a certain amount of information that can be processed at a certain time (22, 25, 26). Just-In-Time (JIT) information presentation principles can be used to avoid unnecessary cognitive load leaving sufficient processing capacity for genuine learning. JIT information presentation means the presentation of information (e.g. a key concept) at the time it is required to perform a task (27-29). This guideline was considered especially useful because the learning material aims at the development of complex cognitive skills. The development of such skills tends to generate cognitive overload unless special measures are taken. Next, including JIT information makes the learning material suitable for students groups heterogeneous with respect to prior knowledge.
The results section describes the learning material that was designed according these guidelines and illustrates how these guidelines influenced the design of the learning material.

<u>Evaluation methods</u>

The learning material was evaluated within academic educational settings against preset criteria as articulated in requirements (Table 2). Students' perception of the learning material was evaluated using agree-disagree questions with a five-point Likert scale. Exam results were analyzed to evaluate whether the learning objectives were achieved (Table 1). The learning material was used in two courses on research methodology in nutritional science. One course was intended for second year BSc students of the Dutch curriculum Human Nutrition and Health. Forty-five students were enrolled in this course. Previous to this course, students attended courses on metabolism, physiology, epidemiology, and research methodology. The other course was intended for first year MSc students of the international curriculum Human Nutrition and Health who did not obtain their BSc degree at Wageningen University and thus did not follow the BSc course described above. Some students obtained a BSc degree related to Human Nutrition, e.g. in nutrition and dietetics or clinical nutrition, others obtained a bachelor degree in life sciences, like clinical medicine or chemistry. Twenty-six students were enrolled in this course. In both courses, 16 hours were scheduled to work on the learning material. During these hours a supervisor was present to observe the students and to answer questions. Besides studying the learning material, students attended lectures, working group sessions on research methodology of intervention studies, and laboratory sessions.

Results

<u>The learning material</u>

Topic of the cases

The digital learning material consists of two cases each built around research questions relevant to Human Nutrition. The first case focuses on the effect of moderate ethanol intake and coronary heart disease and the second case on milk consumption and bone health. These topics were chosen because we expected that they were already familiar for the student and that the relevant physiological and metabolic pathways were covered during their previous education. Furthermore, these topics were assumed to motivate and gain the attention of the students (guideline 1). For the second case, a controversial topic (the ongoing debate on milk consumption and bone health) was chosen to emphasize the relevance of the learning material. This topic was expected to challenge the student and it was observed that it stimulated them to become involved in a scientific debate with their fellow students in which they tried to provide scientific arguments to communicate their opinion with respect to milk consumption. Furthermore, authentic topics and yet unresolved research issues provide opportunities to highlight difficulties that arise when evaluating scientific evidence. It was considered relevant that topics were chosen that provide opportunities for the student to get insight into methodological issues that played a role in research to the effects of foods (like milk intake) versus effects of nutrients (or dietary constituents like ethanol), to short term versus long term effects, to beneficial versus adverse health effects etc

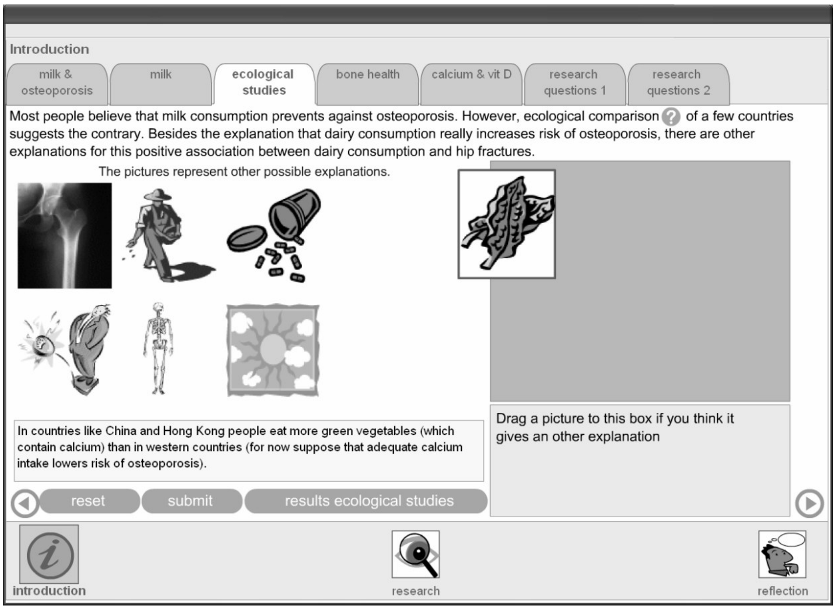

Figure 1: Exercise in the introduction part of case 2. In this exercise the student has to think about alternative explanations of the proposed protective effect of milk consumption on osteoporosis.

Outline of the learning material

Each case consists of interactive exercises which assist students to achieve the learning objectives described above. It starts with an introduction to the topic and research questions. This introduction stimulates the student to think about the relevance of the presented nutritional problem (see Figure 1 for an example of an exercise). Furthermore, the relevant metabolic pathways are presented (e.g. Figure

2). Next, the student arrives at a so-called main screen which gives access to each of the three research approaches (Figure 3). This part aims to assist students in understanding and identifying the characteristics, strengths and limitations of each of the three research approaches separately. To achieve this aim, for each approach, the student outlines a study (Figure 4), interprets results from published studies and draws conclusions with respect to the research question(s). Hereby the student is guided by hints and feedback which points to the strengths and limitations of the approaches. When finished with an approach, the student returns to the main screen where the conclusions of the study are shown. After studying all three approaches the student arrives at the 'critical reflection part' which aims at obtaining insight into the process of evaluating scientific evidence by collating the whole body of presented evidence. Here, the student interprets the (sometimes inconsistent) results from the three research approaches and applies and critical reflect on the methods for evaluating scientific evidence mentioned before. In addition the student is asked to comment on nutritional guidelines regarding alcohol and milk consumption respectively.

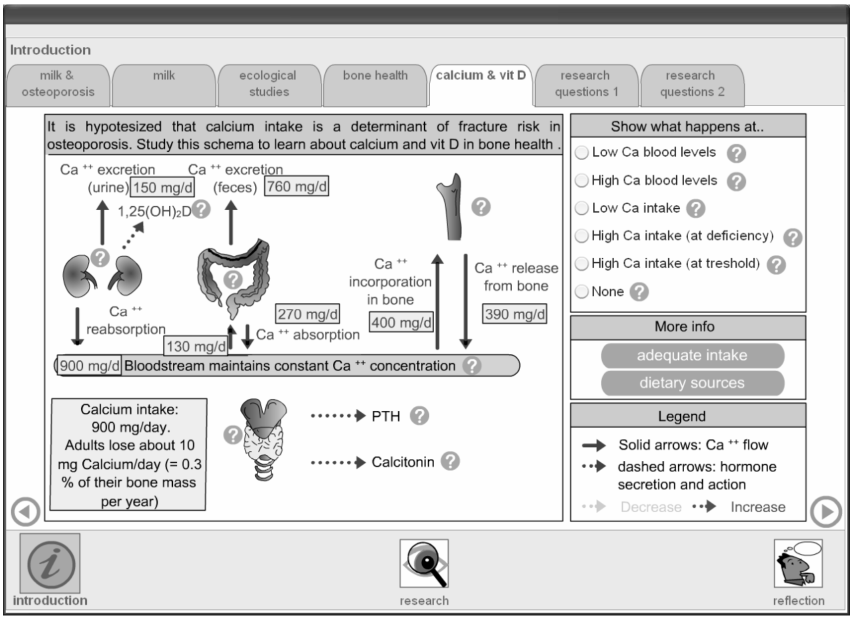

Figure 2: Example of the design pattern for the presentation of information on physiological mechanisms in the introduction part of case 2: calcium metabolism.

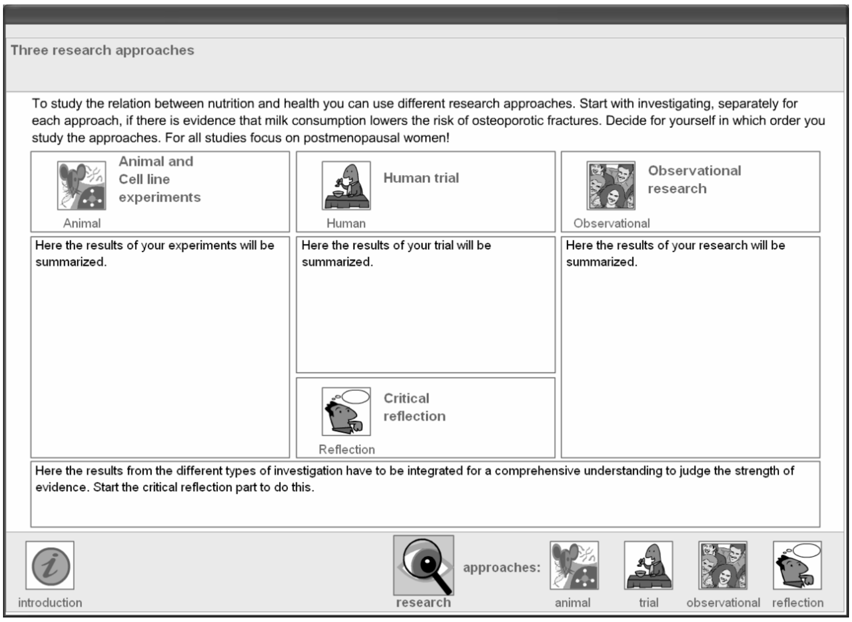

Figure 3: The main screen of case 2. From this screen the student get access to each of the research approaches.

Design patterns

Design patterns are recurrent patterns in the learning material that fit a certain problem or challenge. The concept of design patterns, introduced by Alexander (30), received more attention in education during the last decades (31, 32). Once identified, design patterns can be reused and inspire others in approaching the above described educational challenges.

This section describes patterns for:

1. The presentation of information on physiological and molecular mechanisms.
2. Exercises which support learning how to design a study.
3. Supporting understanding of the different aims of the research approaches.

1: A pattern for the presentation of information on physiological mechanisms.

Figure 2 shows the presentation of information on calcium homeostasis as example of this design pattern. This pattern is also used to present information on bone remodeling, on the vitamin D receptor (case 2), on cholesterol metabolism, on the role of apolipoproteins (case 1) and so on.

Characteristic of this pattern is that the information is visualized into a scheme, animation or picture (guideline 'visualize important concepts'). If additional explanation is necessary, information buttons can be used to display a (short) text or additional visual element within the scheme to reduce or avoid split-attention effects (22, 23, 33). The student can interact with most of the animations. For example, Figure 2 can be modified to study changes in calcium levels. Most visuals are accompanied by exercises to stimulate the student to interact with the information (guideline 'promote active learning'). Furthermore, only information crucial for achieving the learning objectives is presented (guideline 'avoid unnecessary cognitive load'). For example, information on calcium balance and bone remodeling is necessary to understand why results from (long term) observational and (short term) intervention studies to the effect of calcium intake on bone health are different. Finally, the information is made directly accessible at the moment a student needs it (Just-In-Time information presentation).

2. A pattern for exercises which support learning how to design a study or experiment.

Figure 4 gives an example of this design pattern. A similar pattern was used before, in learning material on nutrigenomics (12). The pattern consists of clustered options from which the student should choose the appropriate ones for the design of his study. These exercises aim to support the student in obtaining insight into strengths and limitations of each research approach. The options and feedback provided in the exercise were carefully selected to point the student to characteristics, strengths and limitations of each approach with respect to study design, exposure and outcome measure, inclusion and exclusion criteria, study duration, potential confounding variables etc. After an appropriate study or experiment is developed, an overview of all options is given together with feedback on each option. While each student follows an individualized path through the feedback, this overview could be used to study feedback that was not provided during the exercise.

Several of the guidelines described before influenced the development of this pattern; firstly, the guideline 'promote active learning' played a major role. Furthermore, involving the student in designing an experiment is an authentic task, similar to the tasks of a nutritional scientist which was thought to stimulate the student. Finally Just-In-Time information on the options provided in the exercises is available to avoid cognitive overload.

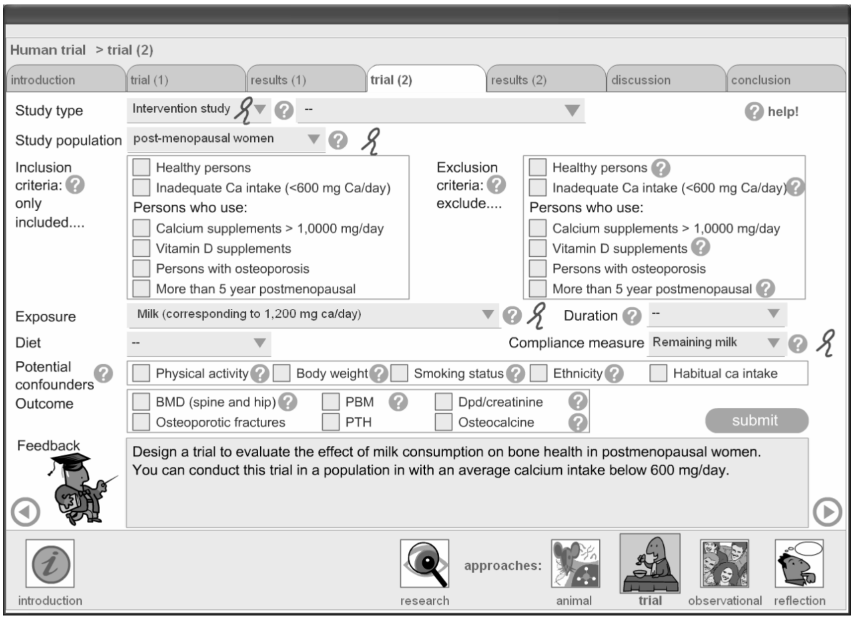

Figure 4: Example of the design pattern for exercises that support learning how to design a study (case 2).

3. A pattern to support understanding of the aims of three common approaches in Human nutrition research.

The biomarker diagram in Figure 5 orders the events between an exposure and a health outcome, together with relevant biomarkers of intake, nutrient status and risk (9). A similar diagram is used in the Process for the Assessment of Scientific Support for Claims on Foods (PASSCLAIM (34)). The biomarker diagram is used for several purposes. First, it is used to point the student to the events between a dietary exposure and a health outcome and the underlying mechanisms. Secondly, it is used to visualize the various aims of the three research approaches. For example, in Figure 5 is visualized that in the case of milk consumption and bone health, the molecular approach mainly aims to unravel mechanisms underlying the proposed effect, human intervention studies aim to investigate the effect of milk consumption on biomarkers for intake or risk and observational studies investigate the effect on the final health outcome. Furthermore, this diagram is used in the critical reflection part to summarize the results from the three research approaches and to identify knowledge gaps in the scientific evidence on the causal relation between the dietary exposure and health outcome under study.

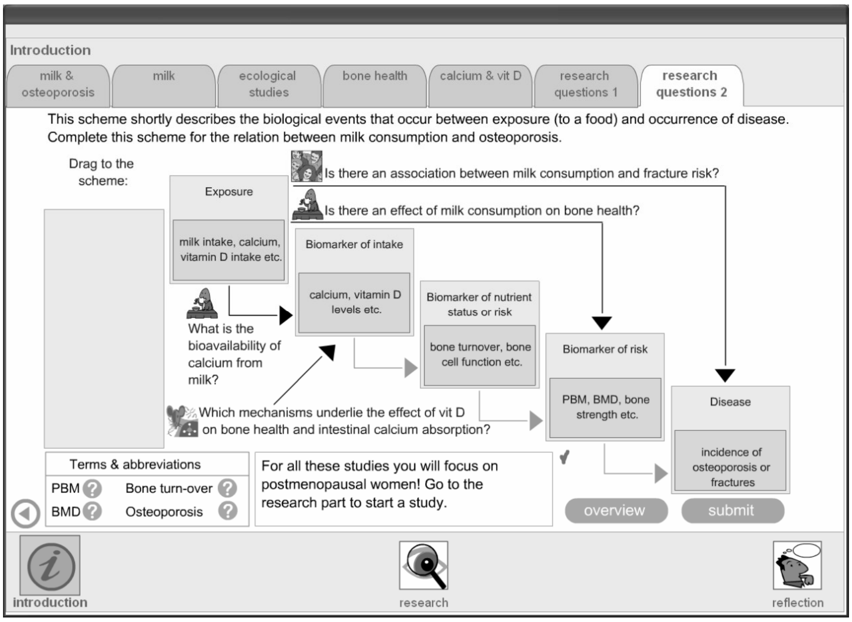

Figure 5: Example of the design pattern to support understanding of the aims of the three approaches in Human Nutrition research: the Biomarker diagram (case 2).

Evaluation results

<u>Exam results</u>

Exam results indicated that 74% of the 45 BSc students were able to explain why research results from the three approaches seems inconsistent by taking into account characteristics, strengths and limitation of the research approaches. 88% was able to evaluate the scientific evidence for the proposed causal relation. Of the 26 MSc students respectively 81% and 65% could answer these questions.

<u>Students perception</u>

Evaluation of the learning material indicated that the learning material fulfils most of the design requirements (see Table 2). In general, the learning material was more appreciated in the MSc course. Furthermore, the MSc students spend about twice as much time on the cases than the BSc students. Furthermore, in both courses the first case was more appreciated than the second case.

More, specifically, the BSc students rated the cases with an overall score of 3.5 (case 1) and 3.0 (case 2) on a five point scale. They indicated that they studied case 1 for on average 3.9 hour during the scheduled hours and case 2 for 3.7 hour and studied an additional 2.3 and 2.8 hour in preparation to the exam. The MSc students rated the cases with an overall score of 4.1 and 3.9 respectively. They indicated that they studied each case for on average 7.8 hour during the scheduled hours and respectively 4.4 to 4.6 hour in preparation to the exam.

Discussion

Activating digital learning material was developed to assist students in obtaining insight into the diversity of approaches in Human Nutrition research and the process of evaluating scientific evidence. During the design of the learning material, principles from theories on learning and instruction were applied. Therefore the learning material serves as an example of how pedagogical sound learning material can be developed. Evaluation studies within educational settings and against preset criteria demonstrated the usefulness of learning material for academic education, because in general students appreciated the learning material and the exam results were in line with our expectations.

It is tempting to provide a detailed explanation of the different evaluation results in both courses (Table 2). However, this should be done with caution as our observational evaluation methods do not allow reliable comparisons because of differences with respect to student's prior knowledge and cultural background, other activities included in the course, teachers involved in the course, course content etc. Nevertheless, the evaluations did give raise to some speculations about observed differences. It became clear that MSc students spend more time on the learning material, appreciated it more and were more motivated than BSc students. A plausible explanation could be that MSc students are in general more motivated because they are more aware of the relevance of their education for their further career. Next, the first case was more appreciated than the second case possibly because case 2 required more knowledge on physiology and metabolism. 30% of the MSc students and 50% of the BSc students indicated that there was insufficient information included on bone physiology, vitamin D and calcium metabolism. Therefore, it could be that students experienced difficulties to solve the exercises and became less motivated. Finally, differences in exam results could be due to the fact that BSc students were allowed to answer in their mother language (Dutch) while the MSc students answered in English which was often not their mother language.

Comparison of the use of the digital learning material with other educational approaches used before was not possible because the learning material introduced learning objectives that were not covered before. In theory it is possible to perform an intervention trial to compare the use of the learning material with other educational approaches. Such trials can provide evidence that the learning material fulfils additional requirements. For example that using the learning material results in better understanding or more efficient learning. However, our evaluations were considered sufficient to demonstrate the value of the learning material for academic education and to justify the implementation into academic curricula. Moreover, intervention trials as described above will not expand our knowledge on how to develop pedagogical sound learning material. Because, like our evaluation method, such trials can not be used to investigate which educational principles can explain the outcome of the learning process. Therefore, we decided to invest into a careful justification of the design decisions grounded into educational principles and theories rather than relying too much on evaluations of the learning material.

In conclusion, development of the learning material resulted in successful introduction of new learning objectives into the curriculum Human Nutrition and Health. Because the learning material required only a few assumptions regarding students' prior knowledge, it is supposed that it could be used within several academic curricula. This is supported by the evaluation results which indicate that students groups heterogeneous with respect to prior knowledge and cultural background benefited from the learning material. Next, the design patterns that were identified are supposed to be reusable for the design of additional learning material. In addition, most of the exercises and schemes can be potentially useful outside the context of digital learning material as a source of inspiration for scientific staff involved in teaching within the field of Human Nutrition.

Acknowledgement

We would like to thank Riet van Rossum for technical development of the learning materials.

Table 2: requirements and evaluation results

Requirement[1,2]	Evaluation question	BSc Case 1 n = 36[3]	BSc Case 2 n = 35[3]	MSc Case 1 n = 25[4]	MSc Case 2 n = 23[4]
		Mean (% 4 or 5)			
Students indicate that the learning material helped them to reach the learning goals.	From this case I learned to identify and discuss strengths and limitations of the three approaches in human nutrition research.	3.7 (60)	3.5 (59)	3.9 (72)	3.9 (70)
	From this case I learned how to evaluate the strength of scientific evidence (for a proposed causal relation between a nutrient or food and a health outcome).	3.5 (53)	3.5 (51)	3.8 (72)	3.9 (74)
Students indicate that they learned a lot from the digital learning material.	I think I learned a lot from this case.	3.2 (44)	3.1 (32)	4.3 (92)	3.9 (65)
Students indicated that the learning material was clear and understandable.	The exercises in this case have been clearly formulated.	3.7 (77)	3.7 (66)	4.1 (96)	3.8 (78)
	The feedback given on my answers was clear.	3.9 (77)	3.6 (56)	4.4 (88)	3.7 (61)
Students indicate that the visualizations helped them to understand important concepts.	The visual aspects in this case helped me to understand important concepts.	4.0 (83)	3.8 (74)	4.0 (76)	4.2 (87)
Students appreciate that the questions and activities in the learning material forced them to become an active learner.	It is good that the questions and activities forced me to become an active learner.	3.6 (60)	3.3 (47)	4.3 (76)	4.2 (83)
Students indicate that the components that require them to become active learners motivate them to study.	The questions and activities raised my motivation to study.	2.9 (26)	2.6 (15)	4.0 (80)	3.7 (65)
Students enjoyed studying the cases.	I enjoyed studying this case.	3.0 (28)	2.6 (21)	4.1 (76)	3.7 (74)
The overall judgment of the learning material was positive.	Overall rating.	3.5 (57)	3.0 (32)	4.1 (88)	3.9 (74)

[1] Requirements were evaluated on a five-point Likert scale (1=totally disagree, 2=partially disagree, 3=neutral, 4=partially agree, 5=totally agree).
[2] An average score of 3 is considered satisfactory while an average higher than 4 is considered excellent.
[3] 45 students followed the course of which respectively 36 (case 1) and 35 (case 2) filled in the evaluation form
[4] 26 students followed the course of which respectively 25 (case 1) and 23 (case 2) filled in the evaluation form

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CHAPTER 7

General discussion

Overview

This thesis addresses how principles derived from theories on learning and instruction guided the design of interactive digital learning materials for academic Human Nutrition Education. Chapters 2 to 6 did describe the design, development and evaluation of learning materials for several sub domains of Human Nutrition. Table 1 gives an overview of the learning objectives of these learning materials. Furthermore, the work presented in this thesis aimed at the development of Pedagogical Content Knowledge (PCK). In this thesis PCK is defined as specific and articulated knowledge on learning problems and core issues in teaching Human Nutrition. PCK articulates how knowledge from the discipline of Learning and Instruction can be applied to Human Nutrition Education. PCK is often implicitly present in the mind of teaching staff. Once PCK is explicitly articulated and further developed it prevents that teaching staff have to invent the wheel again during their teaching activities.

The work described in this thesis differs from the tradition in Human Nutrition research at Wageningen University, in which human intervention studies, mechanistic studies or observational research aim at obtaining knowledge on the relation between food or nutrient intake and a specific health outcome. Therefore, this chapter aims to evaluate the nature of the knowledge that developed during the work presented in this thesis. First the design, development and evaluation of the learning materials is discussed in section 1. This results in recommendations for a systematic approach for the design of digital learning materials. Next, the PCK that was developed is discussed in section 2. This chapter concludes with an overall evaluation of the knowledge that was developed (section 3). The final conclusions are that the learning materials presented in this thesis can be best characterised as examples of 'good – practice' of evidence-based-design, and the PCK as experience-based knowledge, which can be used by teaching staff to guide their actions and decisions with respect to their teaching activities.

Table 1: overview of learning objectives for the learning materials.[1]

Chapter 2: Confounding	Chapter 3: Theory of Planned Behaviour
• Understand the concept of confounding. • Explain under which conditions confounding can occur and why it is necessary to account for it. • Understand that stratification and regression analysis can be used to assess the presence of confounding and to adjust for it.	• Describe the components of the TPB and their relationships. • Give examples of the components of the TPB derived from the field of nutrition behaviour. • Develop a questionnaire, based on the TPB.
Chapter 2 (appendix): adjustment for Confounding	**Chapter 4: Nutrigenomics**
• Analyze a specific exposure - outcome relation for a continuous health outcome. • Detect confounding by simple statistical analysis. • Adjust for confounding using multiple linear regression analysis models. • Understand the rationale behind a general strategy for these analyses.	• Formulate meaningful research questions and develop feasible experiments. • Discuss what is feasible with respect to "personalized diets" and other related topics. • Choose from a predefined set, appropriate tools and techniques for an experiment. • Critically discuss results of micro array experiments.
Chapter 5: Applied Data Analysis	**Chapter 6: Research methodology**
• Identify the appropriate data analysis method for study types relevant to human nutrition research and prepare a protocol for data analysis. • Conduct the statistical analysis as described in the protocol. • Draw conclusions based on results of these analyses.	• Evaluate strengths and limitations of Human Nutrition research approaches. • Design studies or experiments taking into account these strengths and limitations. • Develop insight in the application of, and the rationale behind, models used for collating scientific evidence. • Comment critically on the process of collating scientific evidence.

[1] In this table, the learning materials are ordered based on the cognitive complexity of the learning objective, as is done in Figure 1. Note that this order differs from the chronological order in which the materials were developed and presented in this thesis.

Section 1: Design, development and evaluation

Table 2 gives an overview of the processes which have led to the construction of the learning materials. For each process it is indicated which questions should be given attention. Methodology for the design, development and evaluation of (digital) learning material, is not completely elucidated and still discussed in literature (2-4). Therefore, at first the design and development, was not approached systematically. Gradually, a more systematic approach surfaced. This section discusses the evolution of this approach. The outcomes of the design and development process were (prototypes of) learning materials. Evaluation studies investigated whether the implemented learning materials satisfied specified requirements. This section ends with a discussion of these evaluations.

Table 2: outcomes of the design, development and evaluation process

Design challenge	Design → "Blue print"	Development → Prototype	Evaluation → Product
Aims	Identification and analysis of design challenges, articulation of principles from theories on learning and instruction and IT, design of the learning material.	Development of (prototypes of) digital learning materials, including reusable design patterns.	Evaluation of the learning material against preset criteria and subsequent improvement and further development of the material.
Questions	- Which learning objectives should be covered? - Which learning task should be included? - Which design principles should be used? - How do these principles apply for Human Nutrition Education?	- Is it possible to identify reusable design patterns? - Are there design patterns identified before, which can be reused?	- How should the learning material be evaluated? - How could the learning material be embedded in courses or curricula? - In which education context should the learning material be used?

The design process

Most of the time, the design process started with the identification of a specific design challenge, e.g. an educational problem or an opportunity for the use of digital learning material. Analysis of this challenge resulted in the identification of learning objectives for the learning material, the articulation of design guidelines and the design of a blue print of the learning material.

Systematic approach for the specification of learning objectives

At first, the learning objectives were only explicitly formulated after the design of the learning materials. In fact, design and development provided the means to articulate the learning objectives. As a result, parts of the learning materials had to be redesigned and redeveloped, once the learning objectives were more explicitly formulated. For example, with respect to the concept of confounding, first the material on adjustment for confounding was developed (chapter 2, appendix). The use of this material inspired subject matter experts to discuss which aspects of confounding appeared difficult for students and which learning objectives were therefore considered important. This inspired the formulation of more specific learning objectives and the corresponding design of additional material in which interactive three-dimensional plots were used to explain the conditions for confounding (chapter 2). Consequently, the learning material on adjustment for confounding was redesigned using similar plots.

Gradually, learning objectives were articulated prior to the actual development of the learning materials. Often it was necessary to explore which knowledge and skills should be considered important to teach. Several approaches appeared useful for this exploration such as examining textbooks or scientific literature, performing an extended learning task analysis, discussing learning tasks with subject matter experts etc. For example, in chapter 2 is described how examining the concept of confounding as explained in textbooks, scientific literature and as applied during research, elucidated the aspects of confounding which were considered useful to cover in the learning material. Chapter 5 illustrates how an extended learning task analysis provided input for the development of material in which part task practice was provided in a whole task context.

Next, it appeared that the taxonomy of learning objectives of Anderson *et al* (1) provided a practical framework for detailed articulation and discussion of learning objectives. This taxonomy classifies learning objectives according to two dimensions, the knowledge dimension and cognitive process dimension (See Box 1). It largely corresponds to the intuition of subject matter experts who in general intuitively distinguished at least three types of learning objectives; 'Remembering facts', 'Understanding concepts' and 'Applying procedures'. Especially the listed example verbs (Box 1) could be used easily by subject matter experts. Once it was decided which learning objectives should be covered by the learning material, it was determined if less complex learning objectives than the primary ones should be covered too. The most important reason to include information related to these learning objectives was to minimize necessary prior knowledge. Consequently, the learning material can be used by a target group heterogeneous with respect to prior knowledge. Figure 1 orders the learning material according to the taxonomy of Anderson *et al*, starting with the learning material with the less cognitive complex learning objectives. Note that this order differs from the chronological order in which the materials were developed and presented in the foregoing chapters. Table 3 summarizes the more systematic approach for the selection and articulation of learning objectives as described in this paragraph.

Box 1: Overview of the taxonomy for learning objectives according to Anderson *et al* (1).

Cognitive process dimension

For the cognitive domain of learning (this involves knowledge and the development of intellectual skills) six learning outcomes categories are distinguished. The continuum underlying this dimension is increasing cognitive complexity of the process;

Cognitive process dimension	Description:	Example verbs:
Remembering:	Recall data or information.	Define, identify, list, name, recall, state.
Understanding:	Grasp the meaning of material.	Describe, discuss, explain, give examples.
Applying:	Use that what was learned in a new situation.	Apply, carry out, demonstrate, illustrate, solve, use.
Analyzing:	Understand both the content and structure of the material.	Analyze, categorize, compare, differentiate, outline.
Evaluating:	Make judgments about the value of ideas or materials for a given purpose.	Assess, conclude evaluate, interpret, justify, select.
Creating:	Formulate new structures based on existing knowledge and skills.	Combine, construct, design, develop, generate, plan.

The Cognitive Process Dimensions can be further divided in two till eight sub categories.

Knowledge Dimension

The knowledge dimension contains four categories. These categories are assumed to lie along a continuum from concrete (Factual) to abstract knowledge (Meta - cognitive).

Knowledge dimension	Description
Factual knowledge	Knowledge on terminology, specific details and elements
Conceptual knowledge	Knowledge of classifications and categories, of principles and generalizations, of theories, models and structures etc
Procedural knowledge	Knowledge of subject-specific skills, algorithms, techniques, methods, etc.
Meta - cognitive knowledge	Knowledge of cognition in general as well as awareness and knowledge of one's own cognition

A learning objective can be characterized by these two dimensions as is done in Figure 1.

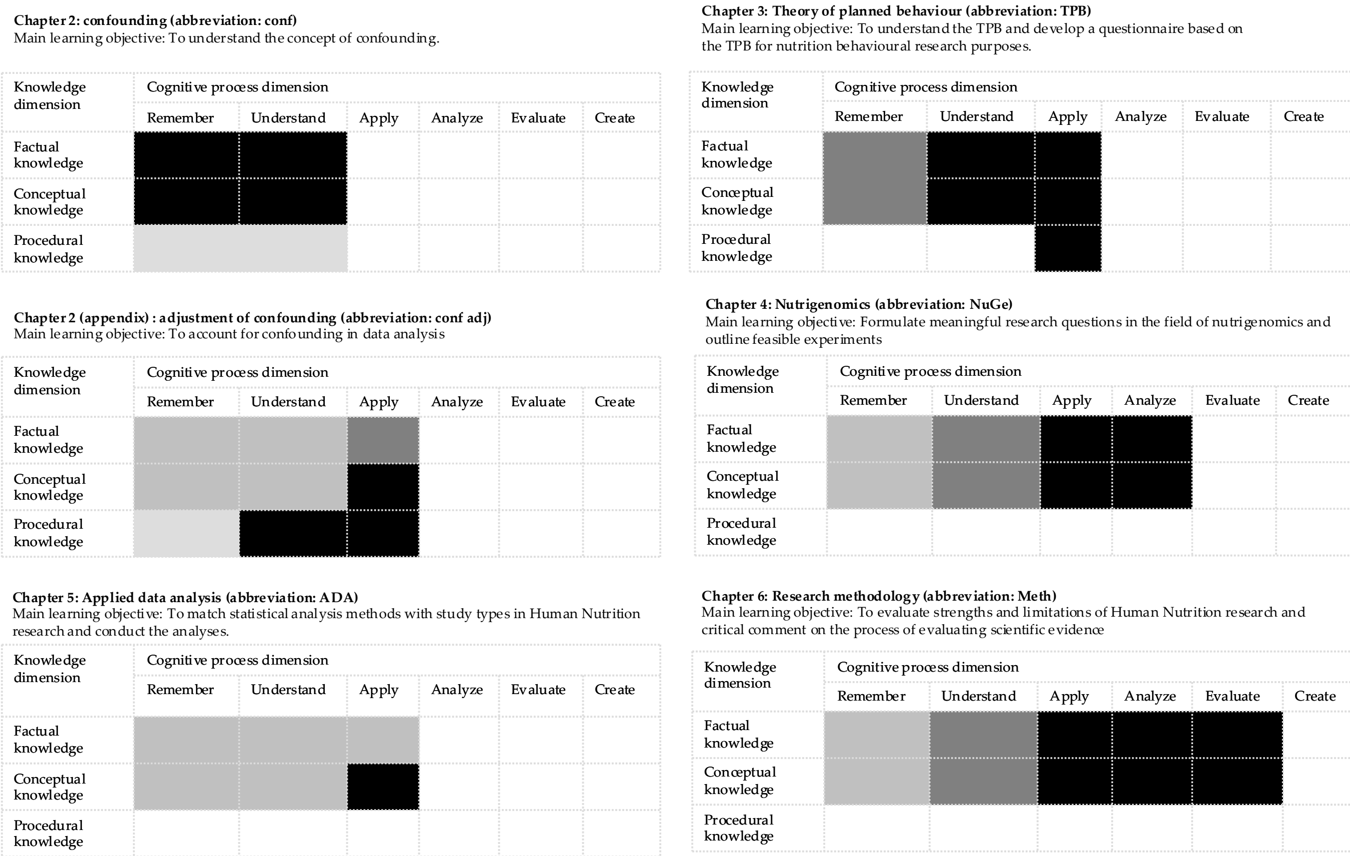

Figure 1: learning objectives of the learning material classified according to Anderson *et al.* (1)

(■ main learning goal, ■ learning goals associated with supportive information. ■ assumed prior knowledge. ■ Procedural information). See chapter 3 and 4 for explanation of the information types.

The fourth knowledge dimension category (meta-cognitive knowledge) is not shown in this figure because the learning materials do not cover learning objectives along this knowledge dimension.

Table 3: Systematic approach for the selection and articulation of learning objectives.

Considerations concerning subject matter
1. To explore which objectives should be covered, an extended learning task analysis, discussion of learning tasks with subject matter experts and review of textbooks and scientific literature could be helpful.
2. The taxonomy of learning objectives of Anderson could be used to specify the learning objectives.
Consideration concerning students' characteristics (e.g. prior knowledge)
3. Take students prior knowledge into account to decide if less complex learning objectives than the primary ones should be covered too.

Systematic approach for the selection of design principles

Table 4 gives an overview of the design principles (formulated as guidelines) which were used during the design of the learning materials. From this table it appears that guidelines which aim at using the opportunities of digital learning material and applying general educational principles, like 'promote active learning' or 'motivate the student', were used for most learning materials. Next, for some learning materials certain guidelines were given more attention than others. For example, it depended on the characteristics of the subject matter, whether the guidelines 'visualize important concepts' and 'use authentic examples or learning contexts' were used. Next, the characteristics of the learning objectives determined which guidelines were considered useful. For example, for learning material that aims at the acquisition of complex cognitive skills, guidelines on the presentation of supportive and procedural information and aiming at reducing cognitive load were considered useful. Finally, student characteristics determined which guidelines were applied. From these patterns, recognized in Table 4 a first attempt to reconstruct a systematic approach for the selection of guidelines for Human Nutrition Education is given (Table 5). Because the articulation of design guidelines for a specific subject matter domain is typically an aspect of PCK, a more extended description of the relation between the guidelines and the subject matter domain Human Nutrition is given in section 2.

Table 4: Overview of guidelines used for the design of the learning material.

no	Guidelines	Conf [1]	Conf[2] (adj)	ADA[3]	TPB[4]	NG[5]	Meth[6]
	1. Use these guidelines as much as possible to apply general educational approaches and use the opportunities of information technology						
1a	Focus on the learning objectives	■	■	■	■	■	■
1b	Motivate the student (ARCS model of Keller)	■	■	■	■	■	■
1c	Promote active learning	■	■	■	■	■	■
1d	Use the characteristics of the information or task to choose an interaction type.	░	░	░	▓	▓	▓
1f	Start each module with an interaction that aims at gaining the attention of the student			░	▓	▓	░
	2. Consider subject matter characteristics to decide whether these guidelines should be applied						
2a	Visualize important concepts when possible	■	■	░	░	░	░
2b	Use authentic examples or learning contexts			▓	■	▓	▓
	3. Consider characteristics of the learning objectives to decide whether these guidelines should be applied						
3a	Use Just-In-Time information presentation	░	░	▓	▓	■	■
3b	Identify supportive and procedural information			■	■	■	■
3c	For supportive information use interactions that can be completed in a few minutes				░	▓	▓
3d	For (part) tasks use interactions with a high degree of freedom				▓	▓	▓
3e	Present supportive information before the learning task				■	■	■
3f	Present procedural information during the learning task		■	■	■		
3g	Identify part and whole learning tasks		■	■	░	░	░
3h	Do not separate supportive information from the learning task.		■	■			
	4. Consider student characteristics to decide whether these guidelines should be applied						
4a	Identify prior knowledge of student	■	■	■	■	■	■
4b	Make information related to assumed prior knowledge available during the learning task.		■	■		■	■

■ Guidelines which played a very important role.
▓ Guidelines which played an important role.
░ Guidelines which played a less important role.
□ Guidelines which played almost no role.
[1] Learning material on confounding (chapter 2)
[2] Learning material on adjustment for confounding (chapter 2: Appendix)
[3] Learning material on Applied Data Analysis (chapter 5)
[4] Learning material on the Theory of Planned Behaviour (chapter 3)
[5] Learning material on Nutrigenomics (chapter 4)
[6] Learning material on Research Methodology (chapter 6)

Table 5: Systematic approach for the selection of design guidelines (see also Table 5).

1. Considerations concerning general educational principles and information technology
- Select guidelines that aim at using the opportunities of digital learning material.
2. Considerations concerning subject matter
- Let subject matter characteristics determine the selection of the guidelines. In general, it is useful that students learn to apply concepts and principles from related scientific disciplines with a Human Nutrition context. Therefore, providing such a context is important.
3. Considerations concerning learning objectives
- For learning material aiming at the acquisition of complex cognitive skills, select guidelines aiming at decreasing cognitive load, the use of JIT information presentation and part task practice. - For learning material aiming at acquisition of factual or conceptual knowledge, present supportive information before the learning task. For learning material aiming at applying procedural knowledge do not separate supportive information from the learning task.
4. Considerations concerning student characteristics
- Let students characteristics determine the selection of the guidelines. Because Human Nutrition Education often has to deal with heterogeneous target groups with respect to prior knowledge, select guidelines on JIT information presentation to make the learning material suitable for these groups.

The development process

At first, there was no clear distinction between the design and development process. Instead of the production of a "blue print", direct realization of the learning material by the designer was practiced. Especially during pioneering design projects as described in this thesis, often direct realization provides new inspiration for further development and improvement of the design. Later on, storyboards were used more and more as "blue print", using techniques similar to those reported by others (5, 6). The use of storyboards made it possible to discuss features of the learning material with subject matter experts before the material was technically developed. Once storyboards were designed and reviewed, the development of learning materials could be left to IT experts. This resulted in more efficient development of the learning materials.

The outcomes of the development process are prototypes of learning materials. Prototypes are build to test (part of) the function of a new design before starting full production. This means that prototypes are not necessarily fully functioning or complete products. After each evaluation study (the prototypes of) the learning materials were improved and refined. The extent of these improvements ranged from layout or language improvements to the redesign of animations, feedback and exercises, but did not involve radical adjustment of the design principles as articulated by the guidelines.

Besides the (prototypes of) learning materials described in the chapters 2 to 6, design patterns are important outcomes of the design and development process. Several design patterns were described for the learning material on Applied Data Analysis (chapter 5) and on Research Methodology (chapter 6). Design patterns are examples of PCK, therefore, the design patterns are further discussed in section 2.

Evaluation of the learning materials

The evaluation studies aimed to evaluate if the learning materials satisfy preset criteria, articulated by requirements, once they are in use. They did not aim to empirically investigate the effectiveness of digital learning material as compared to other materials or other educational strategies. The requirements for the learning materials can be ordered in three groups:

1. Requirements on students' perception of the materials, evaluated with evaluation forms consisting of agree-disagree questions on a five point Likert scale.
2. Requirements on the achievement of the learning objectives, evaluated by exam results of the students.
3. Requirements on properties of the learning materials, evaluated by expert review. However, these latter type of requirements were not evaluated for most materials.

Initial evaluations of the learning materials are described in chapter 2 - 6. In addition, Figure 2 gives an overview of students' perception of the learning materials over the years. For most materials, requirements on students' perception and on the achievement of the learning objectives were fulfilled each time they were used. Therefore, evaluations of the learning material indicated that it is feasible to design, develop and implement digital learning materials for the specified learning objectives and that a specified percentage of the students can achieve these learning objectives.

Observational evaluation studies within an educational setting and against preset criteria limits the usefulness of comparisons between the use of digital materials and other approaches like the use of textbooks or lectures. Comparison with educational approaches used before the introduction of the learning materials is complicated by the fact that besides the introduction of the digital materials, also several other educational changes took place. Furthermore, the characteristics of students enrolled in the course differed from year to year and so on. All these potential confounding factors cannot be eliminated or accounted for. Therefore, valid comparisons between these educational settings are almost impossible.

It is tempting to add further interpretations to the results presented in Figure 2. However, this should be done with caution because our observational evaluation methods do not allow reliable comparisons between the separate evaluations. Nevertheless exploring the evaluation results did give raise to some speculations about observed trends. For example, evaluation results suggested that the learning materials were more appreciated by MSc than by BSc students. Observations of the students who used the materials indicated that BSc students were less willing than MSc students to invest time in studying the learning material. BSc students frequently tried to solve exercises by guessing and only if that was not working invested time to really study the subject. This was less frequently observed among MSc students. The most obvious explanation for this phenomenon is that MSc students are in general more motivated than BSc students because they are more aware of the relevance of the content of the materials for their further career. In general MSc students are allowed to choose which courses or course clusters they attend while for BSc students most courses are obligatory. Another observation was that during the first years in which the learning material was used, students appreciated the learning materials more than students did in later years. A plausible explanation for this observation is that students become used to interactive digital materials because this becomes a more common educational approach. Consequently they do not longer perceive them as novel and innovative.

It is not considered useful to provide more specific explanations for the different results between the evaluation studies, because of the observational nature of the studies and because confounding could not be eliminated.

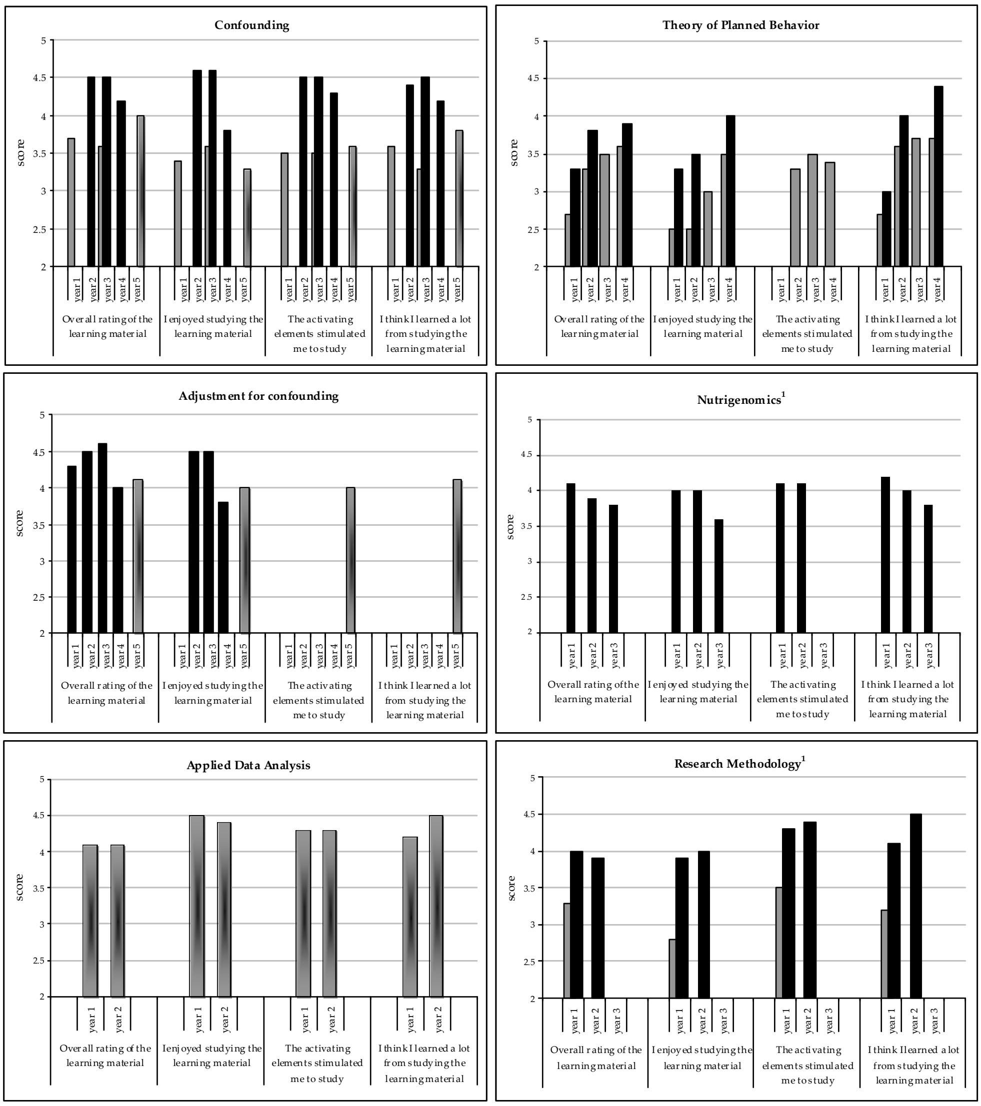

Figure 2: students' appreciation of the learning material.

BSc students MSc students BSC and MSc students in the same course

The materials were evaluated within academic educational settings. Students' perception of the learning material was measured by using agree-disagree questions similar to questions used within Wageningen University to assess students' perception of learning materials, courses and teachers. Within Wageningen University an overall score for a course of 3.5 (on a five point scale), is considered satisfactory, while a score higher than 4.0 is considered excellent.

[1] Average score over two cases.

Section 2: Pedagogical Content Knowledge (PCK)

In addition to the learning materials and their evaluation, the development of PCK was an outcome of the work described in this thesis. Typical examples of PCK are knowing which learning objectives are essential to teach a certain subject matter domain and knowing how learning material should be structured to assist students in achieving the learning objectives. This is described in the previous section and the chapters 2 to 6. The current section gives six additional examples of PCK that was developed. After this, section 3 provides a critical reflection on the design, development and evaluation process and the PCK.

<u>Example 1: Knowledge on frequently occurring misconceptions</u>

Designing learning materials forces the designer to anticipate on frequently occurring misconceptions. Frequently occurring misconception were identified by discussing the topics of the learning material with experienced teachers and (former) students. Also the use of learning material within an educational setting revealed misconceptions. As an illustration two frequently occurring misconceptions are described shortly. One of the misconceptions concerns the supposed idea of many novice students that when a certain variable (e.g. gender) is identified as confounder in one specific study, it always will be a confounder in every observational study. In addition, they assume that this variable could never be an effect modifier. Another misconception concerns the Theory of Planned Behaviour. Many students assume that the component 'normative beliefs' describes the actual expectations of a person's social environment with respect to a certain behaviour. Students often do not realize that this component indicates a person's *own* perception of these expectations, and that this perception not necessarily corresponds with the actual expectations. This confusion leads to misconceptions about the measurement of this component and the interpretation of results from surveys using questionnaires based on the TPB.

<u>Example 2: Knowledge on adequate representations and examples</u>

Another aspect that requires attention during the design of *digital* learning material is the use of representations (e.g. pictures, animations, movie clips, graphs etc) and the use of adequate examples. For example in chapter 2 is argued why three-dimensional plots are an adequate way to present and explain the concept of confounding. In chapter 5 is explained why schemes that directly link the effect measure to the method of data analysis, help students to understand the close relationship between them. Finally, in chapter 6 is explained why the two topics of the learning material on research methodology (alcohol consumption and coronary heart disease; milk consumption and bone health) are appropriate to assist the student in understanding the rationale behind the process of evaluating scientific evidence.

Example 3: Knowledge on useful educational activities

An important guideline followed during the design of the learning materials was to actively involve the student in studying. Consequently, much effort was spend in the development of potential useful interactive exercises. Knowing which activities are likely to be useful for teaching a specific subject matter can be seen as typical PCK. In the chapters 2 to 6 several examples of these interactive exercises are described. For example, chapter 6 describes why the design of experiments was considered a useful activity in order to develop insight in the strengths and limitations of the different approaches often used in Human Nutrition research.

Example 4: Knowledge on subject matter

Because the design of (digital) learning material requires a detailed specification of the subject matter covered by the learning material, scientific staff started to discuss their subject matter. This resulted in more explicit articulation of subject matter knowledge. For example, the design of the learning material on adjustment for confounding (chapter 2, appendix) and for 'Applied Data Analysis' (chapter 5) resulted in the articulation of and agreement on the steps and aspects which have to be distinguished for the development of a data analysis protocol. The use of 3D plots to visualize the concept of confounding, extended experts' knowledge on the conceptual and empirical aspects of confounding.

Example 5: Knowledge on selection of relevant design guidelines

Another aspect of PCK is knowing how educational principles could be applied to Human Nutrition Education. A question asked at the start of our project was if the same design principles (articulated by the guidelines) could be applied to all sub domains in Human Nutrition. This was the reason to develop learning material for each sub domain. To answer this question, first it is analysed whether there is a relation between the selection of the guidelines and characteristics of the learning objectives, subject matter, and student characteristics, as proposed in Table 4 and 5.

Cognitive complexity of learning objectives and selection of guidelines

Some guidelines were derived from or inspired by the Four Component Instructional Design Model (4C/ID) (7, 8) (Table 4, guideline 3a-h). This model offers a structured approach for the design of instructional activities aiming at the acquisition of complex cognitive skills. Therefore, the guidelines derived from the 4C/ID model are only used for the design of learning materials aiming at the acquisition of such skills (i.e. the learning materials aiming at cognitive complex learning objectives: the material on the Theory of Planned Behaviour, on nutrigenomics and on research methodology). For learning materials aiming at less cognitive complex learning objectives (e.g. the learning material on confounding), these guidelines were considered as less useful. Thus, cognitive complexity of the learning objectives determined which guidelines were applied.

Knowledge dimension of learning objectives and selection of guidelines

The learning materials on data analysis (Appendix of chapter 2 and chapter 5) (mainly) aim at the acquisition of procedural knowledge whereas the other materials (mainly) aim at factual knowledge or conceptual knowledge. For these later materials the guideline "Present information supportive for the learning task before the learning task to reduce cognitive load" was considered useful. Consequently the guideline "do not separate the presentation of supportive information from the learning task if this information is closely related to the learning task" was not used. However, this latter guideline appeared useful for the design of materials with objectives along the procedural knowledge dimension. This resulted in materials that stimulate the students to apply supportive knowledge immediately to the learning task which helped them to understand the rationale behind procedures (e.g. for adjustment of confounding). In conclusion, the knowledge dimension of the learning objectives determined which guidelines were considered useful.

Subject matter characteristics and selection of guidelines

Also subject matter characteristics determined which guidelines were considered useful. For example, for the learning material on the 'Theory of Planned Behaviour' the guideline 'Use an authentic Human Nutrition research context' was considered useful because the learning material aimed at understanding the relevance of the TPB for nutrition research. This guideline appeared less useful for the learning material on confounding (chapter 2), because the concept confounding could be applied in the same way for nutritional research as for other observational research. In addition, for this learning material artificial datasets were used. This provides the opportunity to emphasize the effect of confounding by showing extreme and contrasting examples. However, it remains useful to rely not only on artificial examples, but to provide also authentic research examples to show the relevance of confounding (see Chapter 2, Appendix). Another example of how subject matter characteristics determined the selection of guidelines is the use of the guideline 'visualize important concepts'. For example, interactive three-dimensional (3D) plots appeared useful to explain the concept of confounding. Therefore, the whole learning material is based on such plots. Although visualizations were also used in other learning materials, the extent to which visualizations could be used depends, among others, on the characteristics of the specific subject matter.

Student characteristics and selection of guidelines

Characteristics of the intended target group also determined which guidelines were followed. For example, for the learning material on nutrigenomics the intended target group was heterogeneous with respect to prior knowledge. Therefore, the guideline 'Make information related to assumed prior knowledge available during the learning task' was followed. For the learning material on Applied Data Analysis this guideline was also considered useful to make it possible for students to refresh their knowledge or to fill knowledge gaps. For the learning material on confounding this guideline was less relevant because almost no prior knowledge was assumed.

Practical consideration and the selection of guidelines

In addition, practical considerations played a role in determining which guidelines were followed. For example, for the learning material on Applied Data Analysis budgetary constraints limited the flexible use of different interaction types and visualizations. In addition, because the learning materials were developed serial instead of parallel, experiences of the design team with applying the guidelines increased steadily. Gradually, it became possible to follow more guidelines at once. This could have influenced the selection of the guidelines.

Selection of design guidelines and the sub domains of Human Nutrition
Although above a few examples were given of a relation between subject matter and the selection of guidelines, this does not justify a general statement on the relation between selection of guidelines and the sub domains of Human Nutrition. Previous paragraphs illustrated that the selection of guidelines depends on more factors than only the subject matter characteristics. For the sub domain 'nutritional epidemiology' learning materials for low complex learning objectives were developed. For the other domains, learning materials for higher cognitive complex objectives were developed. There is no reason to assume that the domain of nutritional epidemiology covers lower complex learning objectives than the other domains. The selection of low complex learning objectives for this domain was only because of practical reasons. In conclusion, different design principles were applied in successive modules, and for each sub domain only a few learning objectives were covered. Therefore, it is not possible to conclude whether the selection of different design principles was due to differences in subject matter, increasing complexity of the learning objectives, the knowledge dimension of the learning objectives, the students' characteristics, the experiences of the design team etc.

Example 6: Knowledge on design patterns
The final example of PCK is knowledge on reusable design patterns. A design pattern is a recurrent pattern in configurations of components or basic operations that fits a certain problem or challenge (9-11). Several design patterns were described for the learning material on Applied Data Analysis (chapter 5) and on Research Methodology (chapter 6). Next these and other patterns are described to illustrate how general educational principles were applied to Human Nutrition Education.

Design pattern 1: the main screen
Figure 3 gives examples of learning materials in which a so-called "main screen" is used. This screen gives an outline of part tasks which the student has to perform and gives access to these tasks. After each task, the student returns to the main

screen where the results of the task are shown. Gradually, this screen fills with information and provides an overview of all tasks. The main purpose of this screen is to help the student understand the relation between all part task within a whole task context. In the learning materials on Applied Data Analysis and on Adjustment for Confounding, the main screen shows the data analysis steps, the relation between these steps and the results. In the learning material on Research Methodology, the main screen is used to provide an overview of the results from several research approaches, so that the student can easily notice differences and similarities.

Many learning objectives in Human Nutrition Education pertain to the acquisition of complex cognitive skills. For the acquisition of such skills it is useful to provide part task practice in a whole task context (see chapter 5). Therefore, it is hypothesized that a main screen is a useful approach for many other learning objectives in Human Nutrition. For example, it could be useful for additional learning material on data analysis protocols (as in Figure 3a and b), for learning material on nutrigenomics to outline an experimental workflow, for learning material on the design of intervention studies to outline the steps involved in the experimental design and so on.

Design pattern 2: experimental design exercises

In the learning material on Nutrigenomics (chapter 4) and Research Methodology (chapter 6) a design pattern for exercises on the design of an experiment or study is used. This pattern consists of clustered options from which the student should choose the appropriate ones for his (virtual) study. Several of the guidelines described before influenced the development of this pattern. First, the guideline ‘promote active learning’ played a major role. Furthermore, involving the student in designing an experiment is an authentic task, similar to the tasks of a nutritional scientist. Such tasks were thought to stimulate the student. Finally, to reduce the risk of cognitive overload, Just-In-Time information on the options provided in the exercises is available. While many learning objectives in Human Nutrition aim at the acquisition of knowledge and skills related to the design of experiments or studies, it is expected that there will be sufficient opportunities to reuse this pattern.

Design pattern 3: electronic summary or library

The learning materials on Nutrigenomics (chapter 4) and on Research Methodology (Chapter 6) contain a so-called electronic summary or library. Both materials consist of interactive cases in which the student obtains information and acquires skills which are not only relevant in relation to the topic of the case, but which are applicable to many more topics. For example, in the material on Research Methodology the student studies the effect of milk consumption on bone health. By doing this the student obtains knowledge on the strengths and limitation of several research approaches. This knowledge is also relevant for other research topics. Therefore, this widely applicable knowledge is extracted from the cases and presented in an electronic summary. This can be used while studying the cases, as a kind of reference book, or in preparation for the exam. The learning material on nutrigenomics contains an electronic library in which for example information on laboratory techniques, metabolic pathways, physiology etc is summarized. This information is also incorporated in the cases as JIT information.

It can be hypothesized that using such libraries or electronic summaries, promotes transfer of widely applicable knowledge to other topics which are not covered by the cases. Many learning objectives in Human Nutrition Education aim at applying information from related scientific disciplines or at acquiring knowledge on widely applicable research methodologies. Therefore it is useful to present this information not only in an authentic Human Nutrition context, but also less context-bounded, to promote transfer to other Human Nutrition related contexts. Consequently, it is hypothesised that the use of interactive cases together with an electronic summary or library is a valuable approach for developing learning material for Human Nutrition.

Conclusion

In conclusion, the knowledge of an expert designer consists for a large part of many design patterns. Once a design pattern is developed it helps to identify educational problems or challenges and it facilitates the development of learning material by reusing the design pattern. For example, once the design pattern for experimental design exercises was developed for the learning material on Nutrigenomics, opportunities were discovered to reuse this design pattern e.g. in the learning material on Research Methodology.

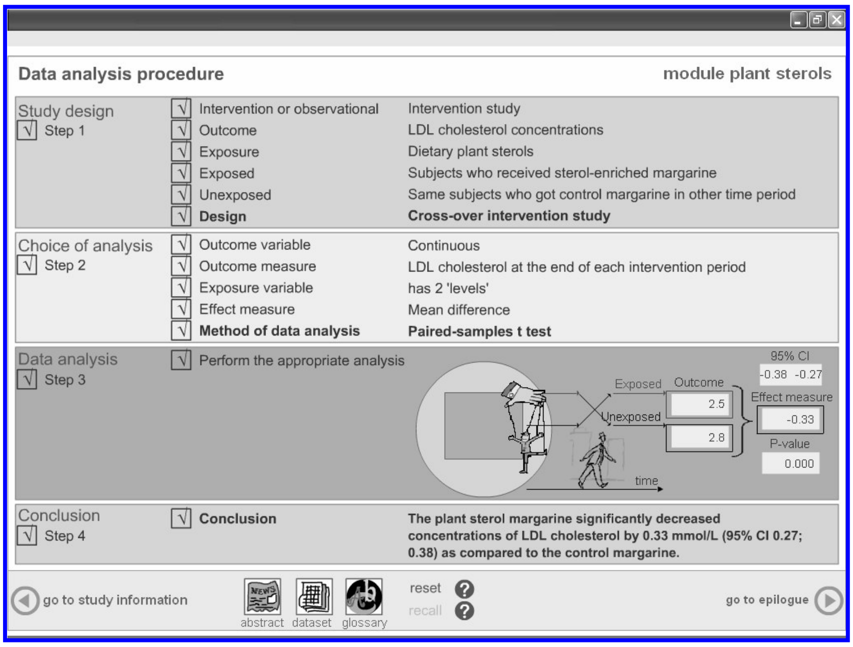

Figure 3a: learning material 'Applied data analysis'

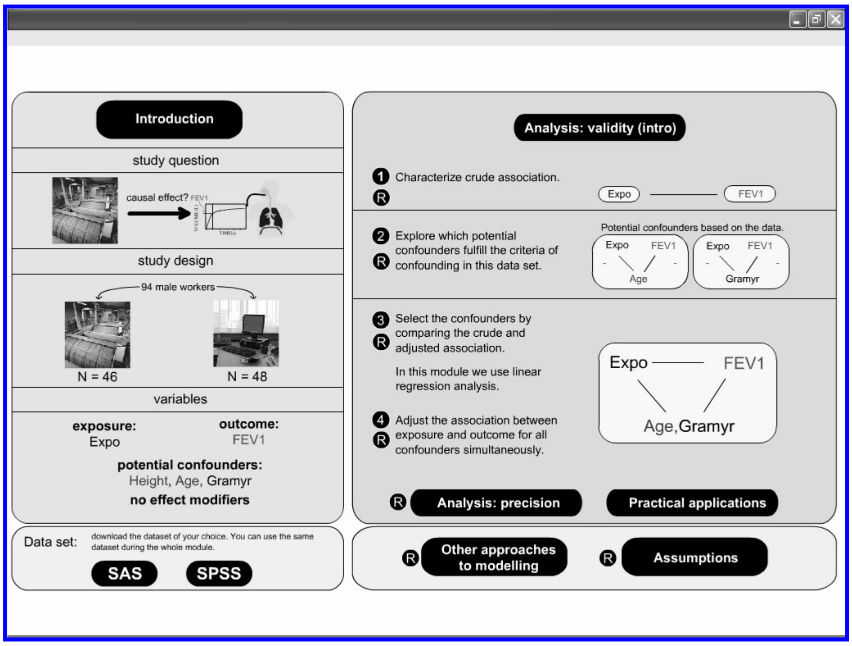

Figure 3: three examples of the design pattern for the so-called main screen

Figure 3b: learning material on adjustment for confounding

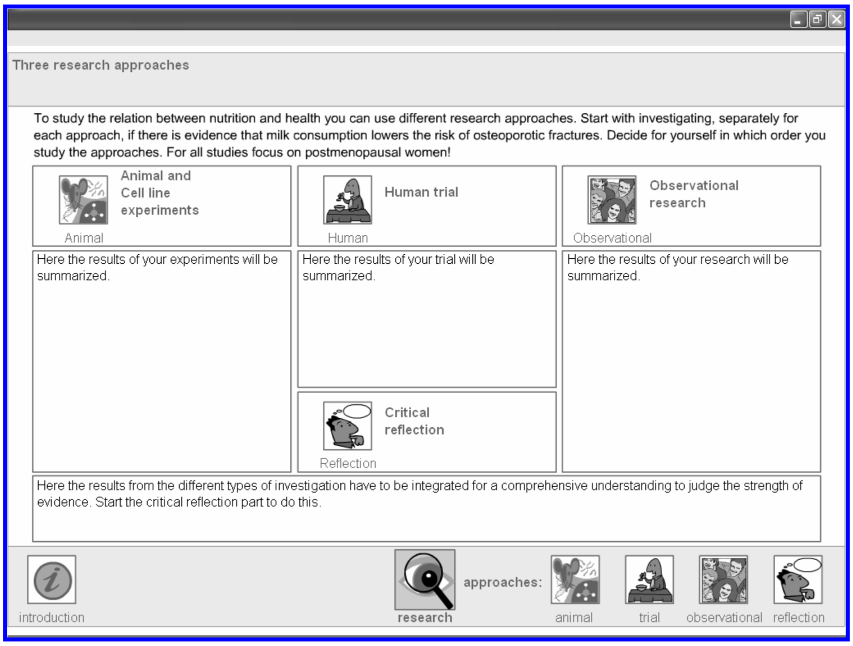

Figure 3: three examples of the design pattern for the so-called main screen (continued)

Figure 3c: Learning material on research methodology.

Section 3: Critical reflection

As mentioned before, the aim of the work described in this thesis was twofold, the development of digital learning materials (section 1) and the development of PCK (section 2). Initially this type of research was characterized as "design-oriented research". Comparison with common research approaches within the domain of Human Nutrition gives rise to another characterization of our research. This section elaborates on this comparison with the aim to evaluate the strength and limitations of our research and to give an accurate characterisation of this research.

<u>Comparison with research approaches in the domain of Human Nutrition</u>

For this comparison, a randomized double blinded controlled intervention trial to the relation between intake of omega-3 fatty acids and cholesterol levels is taken as an example of Human Nutrition research.

Evidence-based design

The first aim of the work presented in this thesis was the design of digital learning material. This design was based on knowledge or evidence derived from educational theories, information technology and the subject matter which is the topic of the learning material. In parallel, a controlled trial as described above, is designed based on research methodological knowledge, knowledge on laboratory techniques (e.g. measurement of cholesterol levels), on nutritional requirements etc. Whether the available evidence is applied correctly and consistently, can be judged by means of expert review.

Whether the final design satisfies its objectives can be evaluated against preset criteria or requirements. Fulfilment of requirements on for example the compliance of the participants and on statistical power indicates that the trial satisfies its objective, i.e. that it is suitable for the investigation of the effect of omega-3 fatty acids intake on cholesterol levels. For the learning material, fulfilment of the requirements on the achievement of the learning objectives and on students' appreciation of the material, indicates that the learning material fulfils its objective, i.e. that it is useful to assist students in achieving the learning objectives and that it is appreciated by the students. Summarized, both, the design of the learning material and the design of the trial can be characterised as evidence based design resulting in a product that fulfils preset requirements. Consequently, these products (the trial and the learning material respectively) can be characterised as examples of 'good-practice'.

Development of new knowledge

During this design process, knowledge, new insights and experience, is developed. For example knowledge with respect to the application of educational theories for Human Nutrition Education (PCK) in case of the learning material, or the application of guidelines for Good Clinical Practice (GCP) and laboratory techniques in case of the trial. The validity of this knowledge can be evaluated by expert review. The practical relevance of this knowledge will become clear when this knowledge is used for the design of new learning materials and trials respectively.

So far, there is a parallel between the design of the learning material and the design of an intervention trial. Once designed, the processes diverge. The trial is implemented to empirically investigate a hypothesis regarding the biological relation between intake of omega-3 fatty acids and cholesterol levels in a specific population. Arguing that the trial was internally valid, in this way new and reproducible knowledge on the effects of omega-3 fatty acids is developed; at least others can try to perform a similar trial and reproduce the results. The evaluation of the learning material did not aim to obtain knowledge on the student population that uses the material (e.g. knowledge on how students learn or how specific educational principles influence learning). In addition, the evaluation did not aim to investigate whether the developed PCK was valid or to provide evidence that applying a specific educational principle or the use of a specific design pattern assist the student in achieving the learning objectives. For this, other evaluation methods should be used, e.g. a comparison of two versions of digital learning material, one in which a specific principle (e.g. JIT information presentation) is applied and one in which it is not applied. However, it was not our aim to perform this type of educational research. Instead, the evaluation of the learning material aims to investigate whether the learning material, based on the whole set of educational principles, fulfils preset criteria thereby illustrating the usefulness of the learning material for educational purposes. For this aim, a controlled trial with the learning material is not necessary.

With respect to reproducibility of PCK, it can for example not be guaranteed that others will identify the same learning objectives or the same representations as potentially useful for Human Nutrition Education (PCK). On the contrary, during the review process of the paper about the learning material on confounding (chapter 2), debate arose whether three-dimensional plots adequately represent the concept of confounding or whether specific aspects of confounding were omitted in these plots which are essential for understanding the concept of confounding. Empirical evaluation of the validity of this PCK is almost impossible. Nevertheless, the design of the learning materials and the subsequent debate developed subject matter experts' knowledge on how to teach confounding, which is a clear example of PCK that could be applied successfully within education.

Conclusion

Although initially characterised as 'design-oriented research' (Chapter 1), the work described in this thesis might be better characterised as 'evidence based design' and the learning materials described in the chapters 2 to 6 as examples of 'good practice'. This more clearly illustrates the strengths of the work, which are the application of educational theories during the design of learning material for a specific subject matter, and the demonstration of the usefulness of these materials.
In this respect the design of learning material can be compared with the design of e.g. a Food Frequency Questionnaire (FFQ). A FFQ is designed based on knowledge of the nutritional composition of foods, on knowledge from cognitive research on formulation of questionnaire items, on statistical methods to calculate nutrient intake etc. Also a FFQ is evaluated against preset criteria (e.g. on reproducibility, costs, user friendliness) to investigate whether it complies with its objective, which is a valid measurement of nutrient or food intake. Consequently, both the design of learning material and the design of a FFQ can be characterised as evidence based designs, and as examples of 'good practice' when the design fulfils present criteria.

<u>Role of PCK for academic Human Nutrition Education</u>

During the design process scientific staff contributed to the development of PCK. They started to share PCK among each other and to use it during their educational practices. To evaluate the work described in this thesis, it is therefore useful to consider the effects of PCK development and the use of digital learning materials on the educational practices at the division of Human Nutrition at Wageningen University. Several examples of these effects are described briefly as an illustration.

First, the design of the learning materials stimulated scientific staff to reflect on their teaching activities. Several mismatches between (intended) learning objectives, learning materials, activities in courses, and exam questions were discovered and repaired. Second, scientific staff became more aware of common misconceptions present by students and adequate approaches to overcome these misconceptions. Third, opportunities for the introduction of learning objectives not covered before were revealed because of the renewed attention for learning objectives, course design, and development of (digital) learning materials. For example, the learning material on nutrigenomics (Chapter 4) was developed because there were no learning materials available which could be used to teach the relatively new subject of nutrigenomics to a target group heterogeneous with respect to prior knowledge. Fourth, the implementation of digital learning material did have several practical consequences. For example, teachers feel that they could focus on more advanced topics in their lectures and that students asked more advanced questions than in other years because the learning material helped the average student to overcome common misconceptions and to understand basic principles. However, these observations are not supported by empirical research. Fifth, digital learning materials can be used to involve students actively in studying without much additional effort of teachers. Finally, using digital learning material could be used to initiate discussions between students and does not necessarily imply that students work individually. For example, during studying the learning material on Research Methodology lively discussions between students started spontaneously because they were triggered by the topic of the case.

Recommendations and further research

Development of learning material and PCK: the process

For future projects it is recommended to focus more explicitly on PCK development. Consequently, for the design of new digital learning materials it is recommended to establish multidisciplinary teams consisting of subject matter and IT experts, and of a PCK expert with knowledge on general educational theories, on the subject matter domain, and on the use of IT. The first task of the PCK expert is the articulation of the learning objectives and the design guidelines, the design of prototypes and the identification of design patterns. Subject matter experts are mainly responsible for the further design of the learning materials within the framework provided by the PCK expert and IT experts are responsible for the technical development. During the later phases of the process the role of the PCK expert should be limited to assisting the subject matter experts in the application of the guidelines, and to the further specification of the guidelines, design patterns and the educational framework when necessary. Furthermore, the PCK expert should stimulate subject matter experts with teaching experience to contribute to the development of PCK. Educational practices of experienced teachers is often based on implicit PCK (e.g. knowledge on common misconceptions and adequate examples). However, to use this PCK for the development of learning materials it should be explicitly formulated and further elaborated. Therefore a subsequent task of the PCK expert is to further develop this PCK and to share it with subject matter experts involved in teaching. This can be done by publishing the PCK in scientific journals and books (like 'teaching epidemiology' by Olson *et al* (12), by giving workshops etc.

Development of learning material and PCK: the content

Most PCK which was developed can be characterised as the application of general educational principles to Human Nutrition Education. It was not in depth investigated whether there are also educational approaches, design patterns, visualisations etcetera, that are specific for Human Nutrition Education. Development of PCK that is more specific than only the application of general educational theories, requires intensive study of the concepts for which learning material is developed, study of related concepts, study of educational principles used before, study of examples used in lectures and in textbooks, extended discussions with scientific staff etcetera. An example of this type of PCK which was developed is the set of interactive three-dimensional plots for teaching confounding (chapter 2). Because the work presented in this thesis covered the broadness of the domain of Human Nutrition and did not allow an in-depth focus on a set of closely related concepts within one sub domain, it was often not possible to develop this type of PCK. Consequently many potential relevant PCK related questions could not be answered. For example,

- Which social-psychological theories on nutritional behaviour should be covered in Human Nutrition Education and in which order should these theories be taught?

- Could the educational approach used to teach the Theory of Planned Behaviour also be used for other theories?
- Could three-dimensional plots be used to explain the concept of effect modification?

In order to develop more specific PCK it could be useful to focus on smaller sub domains of Human Nutrition. In this way, less fragmented, more elaborated and practical applicable PCK knowledge can be developed.

Another aspect of PCK on which it could be useful to focus is the development of examples of supportive and procedural information for specific learning tasks. Many of the guidelines that were followed during the design of the learning materials were related to different JIT information presentation principles for procedural and supportive information (7, 8). However, it appeared not easy to identify supportive and procedural information for specific learning tasks. Documented examples were needed as analogies. However, only a few of such examples were available (13). So far we know, we provided the first examples for Human Nutrition education. It could be useful to develop more of these examples for various learning objectives in Human Nutrition to assist future developers of learning material.

Evaluation of learning materials and PCK

We only evaluated the learning material against preset criteria and did not compare it with other educational approaches. However, in theory it should be possible to perform a intervention study in which the use of the learning material is compared with other educational approaches (as control group) and in which effects on students learning are measured. Such studies can provide empirical evidence that the learning material fulfils additional requirements. For example, the requirement that using the learning material results in better understanding of a specific principle, or more efficient learning compared to other educational approaches. This possibly enlarges the motivation to invest in the development and use of digital learning materials. Yet, such studies will not provide empirical evaluation of the PCK and will not give raise to more knowledge on how to develop evidence-based, pedagogical sound learning material than thus far. Consequently, for further projects we recommend to invest time in enlarging experience with applying existing educational theories and to focus on the development of evidence-based design of learning materials and PCK. We do not recommend more elaborate empirical investigations of the effects of the learning materials than we did thus far. Instead, we recommend expert review of the materials and PCK by e.g. subject matter experts, pedagogical experts and user interface designers.

Educational research

Our work also gives raise to questions which could be answered by more fundamental educational research. For example, our work did give some indications that the optimal timing of presentation of supportive and procedural information (at least partly) depends on student characteristics, especially students' prior knowledge. Van Merrienboer *et al* argue that the optimal timing of information presentation is related to the intrinsic complexity of the information (14). Since (perceived) complexity of information depends on students' prior knowledge, it can be hypothesised that for the timing of information presentation students' prior knowledge should be taken into account (15). Observations during the use of the learning material supported this hypothesis. It was observed that students who lack prior knowledge tended to study first the information in the library before starting with the learning task, while students with more prior knowledge tended to study this information during the learning task. Further research is necessary to investigate this phenomenon and to articulate detailed guidelines with this respect. Other examples of questions that were raised and could be answered by means of educational research are:

- For which learning objectives or which student groups is it useful to use artificial examples (textbook examples) and when should authentic examples be used?
- For which topics or learning objectives should presentational learning objects be used and for which interactive learning objects?
- To which degree should part task practice be offered?

Conclusions

The design and development of the learning materials resulted in experience with the application of general educational principles to the subject matter domain Human Nutrition. Concrete examples are that scientific staff involved in teaching and the designers of the learning material did develop:

- Experience with the explicit formulation of learning objectives.
- Awareness of common misconceptions by students and awareness of educational approaches that can help students to overcome these misconceptions.
- Awareness of representations and examples potential useful to teach a certain concept.
- Experiences with the design of useful activities and exercises.
- Knowledge on design patterns and experience in reusing these patterns.

Knowledge resulted from this experience can be labelled as Pedagogical Content Knowledge (PCK) in the sense that it illustrates how general educational principles can be applied to the subject matter domain of Human Nutrition. Once PCK was developed it appeared relevant to guide the actions and decisions of scientific staff involved in teaching and of developers of learning materials.

The work described in this thesis resulted in the development of interactive digital learning material for several sub domains within Human Nutrition. The design of this learning material can be characterised as evidence-based design, based on knowledge from educational principles, information technology and subject matter. The learning materials can be characterised as examples of 'good – practice' of the application of general educational principles. Evaluation of the learning material within an educational setting and against preset criteria indicated that it fulfilled requirements which were considered indicators of the quality of the learning material. More specifically, in general students were able to achieve the learning objectives of the learning material, and the material was well appreciated by students and scientific staff involved in teaching.

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APPENDIX

Courses within the curriculum of Human Nutrition and Health of Wageningen University

BSc 1: compulsory courses

General courses
- Chemistry for life sciences
- Introduction to statistics
- Cell biology (I & II)
- Human and animal biology
- Consumer and market

Human nutrition courses
- Food and health (I, II, III)
- Metabolic aspects of nutrition

BSc 2: compulsory courses

General courses
- Advanced statistics
- Human and animal biology
- Introduction to social sciences
- Cell biology and health
- Practical biological chemistry
- General toxicology

Human nutrition courses
- Epidemiology and public health
- Food and farma
- Nutrition behaviour
- Applied data analysis
- Methods and applications in human nutrition

BSc 3: one out of three course clusters + additional courses + BSc thesis

Cluster: Mechanisms of nutrition and health
- Food microbiology
- Nutritional physiology
- Advanced metabolic aspects of nutrition
- Food toxicology
- Nutritional genomics and genetics

Cluster: Human nutrition and health.
- Communication and health promotion
- Public health and management
- Food and nutrition security in developing Countries
- Analytical epidemiology
- Public health nutrition

Cluster: Lifestyle in nutrition and health
- Sensory research
- Clinical nutrition
- Exposure assessment in nutrition and health research
- Advances in nutrition behaviour
- Nutrition and sports

MSc 1 / MSc 2 : specialization + MSc thesis + internship

Compulsory (if not followed in BSc):
- Exposure assessment in nutrition and health research
- Epidemiology and public health
- Methodology nutritional research
- Applied data analysis
- Advanced statistics for nutritionists

Specialization: Nutrition in health and disease.

At least one course from:
- Sensory research
- Clinical nutrition
- Advances in nutrition behaviour
- Food and nutrition security in developing countries
- Nutrition and sports

At least one course from:
- Food chemistry
- Nutritional physiology
- Human pathology
- Advanced metabolic aspects of nutrition
- General medicine

Specialization: Public health nutrition

Compulsory:
- Public health and management
- Public health nutrition

At least one course from:
- Communication and health promotion
- Advances in nutrition behaviour
- Food and nutrition security in developing Countries

Specialization: Nutritional and public health epidemiology

Compulsory:
- Analytical epidemiology

At least one course from:
- Human pathology
- Cell physiology and genetics
- Public health and management
- General medicine

Specialization: Molecular nutrition

Compulsory:
- Advanced metabolic aspects of nutrition
- Nutritional genomics and genetics

At least two courses from:
- Comparative immunology
- Gene technology
- Control of cellular processes and cell Differentiation
- Bio information technology
- Nutritional physiology
- Cell physiology and genetics
- General medicine

Specialization: Nutritional physiology

Compulsory:
- Nutritional physiology

At least one course from:
- Cell physiology and genetics
- Behaviour and endocrinology
- Advanced metabolic aspects of nutrition
- Brain and hormones
- Nutrition and sports

Specialization: Food toxicology

Compulsory:
- Food toxicology

At least two courses from:
- Food microbiology
- Gene technology
- Bio information technology
- Cell physiology and genetics
- Advanced metabolic aspects of nutrition
- Food safety
- Nutritional genomics and genetics

SUMMARY

Background

This thesis addresses the design, development and evaluation of interactive activating digital learning materials for academic Human Nutrition Education. It focuses on how principles derived from educational theories guided the design of these materials. In advance it was assumed that the use of digital learning materials could offer several educational and practical benefits. For example, it was assumed that animations and visuals could be used to assist students in understanding methodological research principles and concepts, that interactive exercises could be used to activate each student individually, that feedback could be tailored to the need of an individual student, etc. Therefore, learning material was developed to investigate whether the use of interactive digital learning materials could indeed be valuable for Human Nutrition Education.

The domain of Human Nutrition

Human Nutrition can be defined as the science of foods and the nutrients and other substances they contain, and their actions within the body (including ingestion, digestion, absorption, transport, metabolism, and excretion). The biological aspects of nutrition can be studied on different levels:

1. Nutritional genomics and genetics at the cell, tissue or organ level.
2. Nutritional physiology and clinical nutrition at the individual level.
3. Nutritional epidemiology and public health at the level of the population and the society.

Social and behavioural aspects can be seen as an integral part of the science of nutrition. Research to these aspects focus on the individual level as well as on the level of the population and society.

Educational principles

During the design of digital learning material several educational principles were applied and further articulated for the specific subject matter domain of Human Nutrition. The principles were that the learning material should:

- contain motivational elements;
- stimulate an optimal use of students’ cognitive capacity;
- actively involve the student in studying;
- provide meaningful and authentic learning contexts and learning tasks;
- visualize important concepts and principles if possible.

Chapter 1 of this thesis elaborates on the above described topics. Furthermore, it describes the research and design methodology for the design of the materials.

Aims

This thesis describes the design, development and evaluation of digital learning material for several sub domains of Human Nutrition. More specific:

- The design process aims at the identification and analysis of design challenges and the further articulation and explication of principles from theories on learning and instruction and information technology for several learning objectives in Human Nutrition Education.
- The development process aims at the development of prototypes of digital learning materials and reusable design patterns.
- The evaluation process aims to investigate if the implemented learning material fulfils preset requirements. Furthermore, it aims to identify shortcomings of the learning material and to provide suggestions for improvement.

Learning material and design guidelines

The learning materials were designed iteratively during consecutive design, development, evaluation and revision cycles. They were developed serially to benefit from previous obtained knowledge and experience. The development order was mainly determined by university timetables, to guarantee optimal timing of the evaluation within academic courses and to enable serial development.

For the design of the materials, guidelines based on evidence derived from educational theories and information technology, were identified and further articulated for Human Nutrition Education. Chapters 2 to 6 describe these design guidelines and illustrate how they were applied. Furthermore, these chapters describe the evaluation of the learning materials within academic settings.

Chapter 2 describes learning material that assists students in understanding the concept of confounding. Like all learning materials described in this thesis, this material consists of several interactive exercises, like drag and drop questions, interactive diagrams, animations, multiple choice questions etc. An important characteristic of this learning material is the visual presentation of the concept of confounding by means of interactive three-dimensional plots in which both the empirical and conceptual aspect of confounding are highlighted.

Chapter 3 describes learning material that assists the students in understanding and applying the 'Theory of Planned Behaviour (TPB)'. The main objective was that students learn to apply this theory in a nutrition behavioural context. Therefore, an important guideline was the use of authentic, relevant nutrition research related learning tasks and contexts. For that reason movie clips of interviews on fruit consumption were used to assists students in understanding the TPB.

Chapter 4 describes learning material that assists students in developing skills in the design of nutrigenomics experiments. For the design of this material guidelines aiming at reducing the risk of cognitive overload were articulated and applied. The learning material consists of two cases built around important nutrigenomics topics: personalized diets and the role of free fatty acids in regulation of hepatic gene transcription.

Chapter 5 describes learning material that assists students to match basic statistical analysis methods with intervention and observational study types in Human Nutrition research and to conduct the analysis. This learning material follows guidelines which aim at developing learning material in which part task practice (i.e. practice with the choice of analysis method and the subsequent analysis steps) is provided in a whole task context (the plan of analysis) to assist students in understanding the relations between the part tasks.

Finally, *chapter 6* describes learning material that assist students in evaluating strengths and limitations of common approaches in Human Nutrition research and in obtaining insight in the process of evaluating scientific evidence. For each approach, the student outlines a study with the aim to discover strengths and limitations of the approaches. Next, the student assembles the whole body of evidence provided by the three research approaches and applies and critically reflects on the methods for evaluating scientific evidence. For this learning material most of the design guidelines articulated before were applied.

A demo website gives access to examples of the above described learning materials: http://pkedu.fbt.wur.nl/cora/demo-thesis/

Evaluation of the learning material

The learning materials were evaluated against preset criteria, within academic educational settings. These evaluations indicated that the learning material fulfils it purposes. In general students were able to achieve the learning objectives of the learning material. In addition, during most evaluations the learning material was well appreciated by the students. For example, students indicated that they learned a lot from the learning material and that they appreciated the activating, motivating and visual elements in the material. Furthermore, subject matter experts evaluated the scientific and educational content of some of the learning materials. In general this evaluation was positive.

Pedagogical content knowledge (PCK)

In addition, the development of PCK was an outcome of the work described in this thesis. PCK is specific and articulated knowledge on problems, core issues and the application of general educational theories in teaching Human Nutrition. For example, during the design, development and implementation of the learning material on confounding (chapter 2) it became clear which aspects of confounding were considered useful to cover in the learning material, which aspects were difficult to understand for students, and which learning tasks, examples, visualizations and educational approaches were potential useful to assist students in understanding confounding and to overcome common misconceptions. Also during the design of the other learning materials this type of PCK was developed.

Next, the identification of design patterns is a typical example of PCK that was developed. A design pattern is a recurrent pattern in configurations of components or basic operations that fits a certain type of problem or challenge and which can be reused. Examples of design patterns that were developed are specific types of interactive exercises e.g. exercises that support learning how to design studies or experiments, and a specific principle of the presentation of information e.g. visual information presentation on physiological en metabolic pathways.

Chapter 7 gives a more extended description of the PCK which was developed. Furthermore this chapter evaluates the strengths and limitations of the work described in this thesis and gives suggestions for further development of PCK and learning materials.

Conclusions

The work described in this thesis provides an illustration of evidence-based design of interactive digital learning material for academic Human Nutrition Education by applying educational theories. The learning materials serve as examples of 'good-practice'. Evaluation of the learning material within an educational setting and against preset criteria indicated that it fulfilled its purposes. The design process revealed the need to develop PCK and at the same time provided the means to develop it. Moreover, this PCK appeared relevant to guide the actions and decisions of academic teaching staff and of developers of learning materials.

SAMENVATTING

Achtergrond

Dit proefschrift beschrijft het ontwerp, de ontwikkeling en evaluatie van interactief digitaal leermateriaal voor het vakgebied 'Humane Voeding'. Uit literatuur en praktijkervaringen is bekend dat digitaal leermateriaal geschikt kan zijn om studenten te helpen ingewikkelde onderwerpen, begrippen en methodes beter te leren begrijpen. Daarnaast zou digitaal leermateriaal geschikt zijn om studenten te motiveren en te activeren door middel van voor het gebruik van interactieve oefeningen, plaatjes, animaties, schema's, filmpjes enz. Door middel van het ontwikkelen van digitaal leermateriaal wilden we erachter komen wat de waarde van dergelijk leermateriaal zou kunnen zijn voor academisch onderwijs op het vakgebied van de Humane Voeding.

Het vakgebied Humane Voeding

Humane Voeding is het wetenschapsgebied dat voeding, bestanddelen in de voeding, voedingspatronen en hun effecten in het lichaam bestudeert.

De biologische effecten van voeding kunnen bestudeerd worden op drie niveaus:

- Het niveau van de cel, weefsel of het orgaan. Hieronder valt ook het relatief nieuwe vakgebied 'nutrigenomics' dat zich vooral richt op het begrijpen van de moleculaire werkingsmechanismen van voeding.
- Het niveau van het individu. Dit vakgebied richt zich vooral op het begrijpen van de werking van voedsel en voedingstoffen in het lichaam en het bevorderen van een gezond voedingspatroon.
- Het niveau van de populatie. Dit vakgebied noemen we epidemiologie. Het richt zich vooral op het begrijpen van de relatie tussen voeding en gezondheid binnen bevolkingsgroepen.

Op het niveau van het individu en de populatie kunnen ook de sociale- en gedragsaspecten die de voedselkeuze beïnvloeden bestudeerd worden.

Onderwijskundige principes

Tijdens het ontwikkelen van het leermateriaal zijn algemene onderwijskundige principes toegepast en verder gespecificeerd. De belangrijkste principes waren:

- Het leermateriaal dient motiverende elementen te bevatten;
- Het leermateriaal moet een efficiënt gebruik van de cognitieve capaciteit van de student stimuleren en onnodige belasting voorkomen;

- Het leermateriaal moet zo ontworpen zijn dat de student gestimuleerd wordt om actief bij het leren betrokken te zijn;
- Het leermateriaal moet gebruik maken van authentieke leeromgevingen en leertaken die relevant zijn voor de student;
- In het leermateriaal moet waar mogelijk gebruik worden gemaakt van de mogelijkheden die digitaal leermateriaal biedt met betrekking tot het gebruik van visualisaties.

Bovengenoemde onderwerpen zijn in hoofdstuk 1 van dit proefschrift beschreven. Daarnaast wordt er in dit hoofdstuk een overzicht gegeven van de ontwerpmethodes die gebruikt zijn.

Doelen

Het doel van het werk beschreven in dit proefschrift, was om digitaal leermateriaal te ontwerpen, voor diverse onderwerpen over de volle breedte van het vakgebied 'Humane Voeding'. Het doel van het ontwerpen van het leermateriaal was om algemene onderwijskundige principes te identificeren en verder uit te werken zodat deze toegepast konden worden bij het ontwerp en de ontwikkeling van leermateriaal voor onderwijs in de humane voeding. Bij het ontwikkelen van het leermateriaal was het belangrijk om na te gaan of er bepaalde patronen in het ontwikkelde leermateriaal te ontdekken zijn die steeds opnieuw toegepast kunnen worden tijdens het ontwerpen van nieuw leermateriaal. Tenslotte werd het leermateriaal geëvalueerd met als doel om na te gaan of het leermateriaal aan vooraf opgestelde criteria voldoet en om eventuele tekortkomingen te identificeren en te verbeteren.

Leermateriaal en ontwerprichtlijnen

De hoofdstukken 2 tot 6 beschrijven het leermateriaal dat ontworpen is en onderbouwen de ontwerpkeuzes die gemaakt zijn. Voor elk van de leermaterialen zijn ontwerprichtlijnen beschreven en is uitgelegd hoe deze zijn toegepast. Deze richtlijnen zijn afgeleid van de hierboven beschreven algemene en van meer specifieke onderwijskundige principes. Daarnaast wordt voor elk leermateriaal beschreven hoe het gebruikt en geëvalueerd is tijdens het onderwijs dat verzorgd wordt aan de Universiteit van Wageningen. De leermaterialen zijn beschreven in de volgorde waarin ze ontwikkeld zijn.

Hoofdstuk 2 beschrijft leermateriaal dat de studenten helpt om het concept 'confounding', een belangrijk concept in epidemiologisch onderzoek, te begrijpen.

Zoals al het leermateriaal beschreven in dit proefschrift, bestaat het leermateriaal uit een scala van interactieve oefeningen, zoals meerkeuzevragen, sleepvragen, animaties en simulaties. Verder is in dit leermateriaal gebruik gemaakt van de mogelijkheden om te visualiseren. Het concept confounding wordt namelijk uitgelegd door gebruik te maken van interactieve driedimensionale grafieken die de student kan manipuleren.

Hoofdstuk 3 beschrijft leermateriaal dat er op gericht is de student te helpen de 'theorie van gepland gedrag' te begrijpen en toe te passen. Deze theorie wordt gebruikt om gedrag van mensen te onderzoeken en te verklaren. Een belangrijk leerdoel voor dit leermateriaal was dat studenten leren deze theorie toe te passen in voedingskundig onderzoek. Daarom is in dit leermateriaal veel aandacht besteed aan het aanbieden van relevante voorbeelden op het gebied van voedingskundig onderzoek. Hierbij is gebruik gemaakt van filmpjes waarin interviews met studenten over fruitconsumptie getoond worden. Daarnaast zijn richtlijnen toegepast die gericht zijn op het voorkomen van onnodige belasting van de cognitieve capaciteit van de student.

In *hoofdstuk 4* zijn deze richtlijnen meer in detail uitgewerkt en toegepast bij het ontwerpen van leermateriaal dat studenten helpt vaardigheid te verwerven in het ontwerpen van nutrigenomics experimenten. Dit leermateriaal bestaat uit twee cases. In de eerste case leert de student wat (on)mogelijk is met betrekking tot het verstrekken van voedingsadviezen specifiek toegesneden op het genetische profiel van een persoon. De tweede case gaat dieper in op de rol van vetzuren bij het aansturen van processen in de lever.

Hoofdstuk 5 beschrijft leermateriaal dat studenten leert op grond van de opzet van een studie de juiste statistische methode te kiezen voor analyse van de resultaten. Voor dit leermateriaal zijn ontwerprichtlijnen toegepast die zich richten op het ontwikkelen van leermateriaal waarin de mogelijkheid tot het oefenen van deeltaken (het kiezen en uitvoeren van de juiste analyse methodes) aangeboden wordt binnen het kader van de complete taak (het opstellen en uitvoeren van een volledig analyse plan).

Tenslotte beschrijft *hoofdstuk 6* leermateriaal dat de student helpt om de sterke en zwakke punten in voedingskundig onderzoek te identificeren, en tijdens het ontwerpen van studies daarmee rekening te houden. Een belangrijk leerdoel van dit leermateriaal is dat studenten leren kritisch de resultaten van verschillende benaderingen in het voedingskundig onderzoek te beoordelen. Voor het ontwerp van dit leermateriaal zijn de meeste van de eerder opgestelde ontwerprichtlijnen toegepast. Daarnaast is er vooral aandacht besteed aan het identificeren van patronen die herkenbaar zijn in de leermaterialen met als doel deze te hergebruiken.

Een deel van het leermateriaal kan bekeken worden via een demosite: http://pkedu.fbt.wur.nl/cora/demo-thesis/

Evaluatie van het leermateriaal

Het leermateriaal is geëvalueerd in verschillende vakken die georganiseerd werden door de afdeling Humane Voeding van Wageningen Universiteit. Voorafgaande aan de evaluatie zijn criteria opgesteld waaraan het leermateriaal zou moeten voldoen. Over het algemeen wezen de evaluatiestudies uit dat de studenten positief waren over het gebruik van het leermateriaal. De studenten gaven aan dat ze veel van het leermateriaal leerden, dat het hen activeerde en motiveerde om te studeren. Kortom ze vonden het leuk om het leermateriaal te gebruiken en waardeerden vooral de interactieve en visuele elementen in het leermateriaal. Uit examenresultaten bleek verder dat voldoende studenten de leerdoelen van het leermateriaal behaalden.

Daarnaast is een deel van het leermateriaal beoordeeld op wetenschappelijke inhoud en didactische waarde door experts in het vakgebied. Over het algemeen was ook deze beoordeling positief.

Vakdidactiek

Het ontwerpen, ontwikkelen en gebruiken van het leermateriaal heeft geleid tot het ontstaan van vakdidactische kennis. Dit is kennis die beschrijft wat veel voorkomende problemen zijn in het onderwijs op een bepaald vakgebied en hoe algemene onderwijskundige principes toegepast kunnen worden. Tijdens het ontwerpen van het leermateriaal voor confounding (hoofdstuk 2) werd bijvoorbeeld duidelijk welke aspecten van het concept confounding belangrijk zijn om aandacht aan te geven in het onderwijs. Daarnaast werd duidelijk welke aspecten lastig waren voor de studenten om te begrijpen en welke leertaken, voorbeelden, visuele middelen en onderwijskundige benaderingen nuttig waren om de student te helpen en vaak voorkomende misverstanden uit de weg te ruimen. Ook tijdens het ontwerpen en ontwikkelen van de andere leermaterialen ontstond dergelijke vakdidactische kennis.

Ook de identificatie van terugkerende patronen in het leermateriaal is een voorbeeld van vakdidactische kennis. Voorbeelden van dergelijke patronen zijn een specifiek type oefeningen, een specifieke manier van het gebruik van visualisaties, een patroon in de timing van de presentatie van informatie enz. Wanneer dergelijke patronen geïdentificeerd zijn kunnen ze hergebruikt worden tijdens het ontwikkelen van nieuw leermateriaal waarin soortgelijke leerdoelen een rol spelen.

Al deze vakdidactische kennis kan gebruikt worden door degene die betrokken zijn bij het academisch onderwijs en bij het ontwerpen van leermateriaal op het vakgebied van de Humane Voeding. *Hoofdstuk 7* geeft een uitgebreide beschrijving van deze vakdidactische kennis. Daarnaast worden er in dit hoofdstuk aanbevelingen gedaan voor vervolgonderzoek en wordt er kritisch teruggeblikt op de methodes die gevolgd zijn tijdens het ontwerpen, ontwikkelen en evalueren van het leermateriaal.

Conclusies

Het werk beschreven in dit proefschrift laat zien dat het goed mogelijk is om interactief digitaal leermateriaal te ontwikkelen voor academisch onderwijs op het vakgebied van de Humane Voeding door het toepassen van algemeen onderwijskundige principes. Dit leermateriaal is positief ontvangen door zowel studenten als docenten. Daarnaast bleek tijdens het ontwerpen van de leermaterialen dat vakdidactische kennis essentieel is om goed leermateriaal te kunnen ontwikkelen. Tegelijkertijd bleek het ontwerp, ontwikkelen en gebruiken van deze leermaterialen een geschikt middel om onze vakdidactische kennis te vergroten.

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Met veel plezier kijk ik terug op mijn AIO periode. Ik kan mij nog goed herinneren dat toen mijn huidige promotor Pieter van 't Veer mij vroeg of 'onderwijs' niet iets voor mij was ik niet erg enthousiast reageerde, omdat ik 'onderwijs' onmiddellijk associeerde met 'voor de klas staan'. Na 5 jaar vakdidactisch promotieonderzoek ben ik er achter gekomen dat onderwijs veel meer is. Nu weet ik dat het ontwerpen van onderwijsmateriaal en het begeleiden van de studenten die dat materiaal gebruiken zeker wel wat voor mij is.

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Bedankt!

Cora

ABOUT THE AUTHOR

About the Author

Cora Busstra was born on 10 May, 1979 in Utrecht. After completing secondary school in 1997 (gymnasium, Gereformeerde Scholengemeenschap "Guido de Brès", Amersfoort), she studied Biology at Wageningen University. During her study she first specialized in Theoretical Biology. As part of this specialization she worked on the development of a predictive model for the distribution of the corn rootworm in Europe. Second, she specialized in Nutritional Epidemiology and conducted epidemiological data analysis on fish fatty acids and colorectal adenomas in a case-control study. Furthermore she participated in research on familial breast cancer at the 'Netherlands Cancer Institute' (Amsterdam) and 'the Department of Medical Genetics' (UMC, Utrecht). Besides, she participated in a project on the development of learning material for biology education and wrote a short report on the use of digital learning material.

Following her graduation in September 2002, she started her PhD at the Division of Human Nutrition on the development of interactive digital learning material for academic Human Nutrition Education. Besides the work described in this thesis, she had an advisory role in a project on the development of learning material for epidemiology for higher vocational education. Furthermore, she contributed to the design of learning material for Nutrigenomics Education within the European Nutrigenomics Organization (NuGO), in collaboration with the Technische Universität of München (Germany) and University of Oslo (Norway).

Since September 2007, Cora works at the division of Human Nutrition on the development of digital learning material in collaboration with NuGO, EuroFIR (European Food Information Resource Network) and EURRECA (Network of Excellence: European micronutrient Recommendations Aligned).

Publications on Human Nutrition Education

Busstra, M.C., de Graaf, C., and Hartog, R. (2007), Design of Digital Learning Material on Social-Psychological Theories for Nutrition Behavior Research. Journal of Educational Multimedia and Hypermedia, 16, 163-182.

Busstra, M.C., Hartog, R., Kersten, S., and Müller, M. (2007), Design Guidelines for the Development of Digital Nutrigenomics Learning Material for Heterogeneous Target Groups. Advances in Physiology Education, 31: 67-75.

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Other publications

Busstra, M.C., Siezen, C.L.E., Grubben, M.J.A.L., Kranen, H.J. van, Nagengast, F.M., Veer, P van 't (2003), Tissue levels of fish fatty acids and risk of colorectal adenomas: a case-control study (Netherlands). Cancer Causes Control, 14: 269-76.

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Overview of completed training activities

(Graduate school VLAG)

Discipline specific courses

Educational:

- General didactics (Wageningen 2002, 2003)
- Education days (SURF Collaborative organization for higher education institutions and research institutes in the Netherlands, 2002, 2003)
- Workshop: digital learning material for statistics education (ESPELON, Amsterdam, 2004)
- Seminar: Digital University (DU, Amersfoort, 2004)
- Conference: simulations, gaming and cases: authentic learning in higher education (SURF, Amsterdam, 2006)

IT:

- Flash Masterclass (Waardenburg, 2002)
- Flash seminars (Macromedia, 2003, 2004, 2005)

Human Nutrition:

- Annual meetings of the Netherlands Epidemiology Society (2003, 2004, 2005)
- Masterclass nutrigenomics (VLAG, Wageningen 2003)
- Seminar: SNPs in diet related disease (RIVM, Bilthoven, 2004)
- Nutrition congress (Amsterdam, 2006)
- Mini-Symposium: Nutrition and antisocial behaviour among young adult prisoners (Division of Human Nutrition, Wageningen 2004)

General courses

- Course: communication and collaboration (KLV, Wageningen, 2006)
- PhD student week (VLAG, Bilthoven, 2002)
- Written English (CENTA, Wageningen, 2003)
- Presenting skills (CENTA, Wageningen, 2004)

Optional activities

- Preparation of PhD research proposal (Wageningen, 2002)
- Meeting of Journal Club (Division of Human Nutrition, Wageningen, 2002-2006

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