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

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Busstra MC, Hartog R, Kersten S, Müller M. Design guidelines for the development of digital nutrigenomics learning material for heterogeneous target groups. *Adv Physiol Educ* 31: 67–75, 2007; doi:10.1152/advan.00090.2006.—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 study 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: *1*) the formulation of meaningful research questions in the field of nutrigenomics and *2*) the development of feasible experiments to answer these questions. The learning material consists of two cases built around important nutrigenomics topics: *1*) personalized diets and *2*) the role of free fatty acids in the 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.

instructional design; Just-In-Time information presentation; multimedia; nutritional genomics; computer-assisted instruction

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 to unravel the mechanisms underlying the physiological and molecular effects of nutrients (10). 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.

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 that 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, Refs. 2, 5, and 17). Without extensive prior knowledge of the 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, this again 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 fulfill these needs, new interactive digital learning material was developed with the specific aims to introduce the subject of nutrigenomics, emphasize the mul-

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tidisciplinary nature of nutrigenomics, reduce the problem of a heterogeneous target audience, and stimulate the involvement of students in studying nutrigenomics and nutrigenomics research. This study describes the digital learning material and its design, development, implementation, and evaluation to provide guidance for successfully introducing interactive digital learning material for teaching nutrigenomics or related scientific disciplines.

MATERIALS 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 previously (3, 4). 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 were consistent with the guidelines (see Table 1). The next sections 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 learning goals and objectives is an important part of the design process (11). 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 were 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 was 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 needed to acquire and use knowledge about various nutrigenomic-related subjects. For each

Table 1. *Guidelines, requirements, and evaluation questions*

Guidelines	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 digital 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 nutrigenomics research (*case 1*) or a nutrigenomic experiment (*case 2*).
	R1D. Experts confirm that the scientific quality of the learning 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 just-in-time information presentation.	*R3.* Students indicate that the digital learning material is clear and understandable.	The excercises were clearly formulated. The feedback given on my answers was clear. The case links up well with what I already knew.
G4. Promote active learning by stimulating the student to perform the activities.	*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 the visualization helps them to understand important concepts.	The visual aspects in this case helped me to understand important concepts.
	R5B. Experts confirm that the visualization of important concepts is in keeping with their own understanding of these concepts.	
	R5C. Experts in nutrigenomics confirm that the screen layout, colors, pictures, etc. are adequate.	N/A†
	General requirements	
	R6. Students enjoyed the digital learning material.	I enjoyed studying this cases.
	R7. The general judgment of the digital learning material by students was positive.	Overal rating of the case (where *1* was poor and *5* was excellent).
	R8. Experts in nutrigenomics confirm that the 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 are clear.	N/A†

Evaluation questions used a 5-point Likert scale (*1,* totally disagree; *2,* partially disagree; *3,* neutral; *4,* partially agree; and *5,* totally agree). Requirements were considered to be fulfilled when the average rating was ≥4.0 and at least 75% of students gave a rating of *4* or *5.* N/A, not applicable. *This requirement was evaluated by analyzing student exam results. Exams were scored on a 10-point scale. Requirement R1A was considered to be fulfilled when the mean scores was >8.0 and <10% of the students had a score <*6.* †These requirements were evaluated by experts in nutrigenomics using several evaluation questions and interviews.

Table 2. *Learning goals, objectives, and learning tasks 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	After studying the learning material, the student must be able to do the following:
	Explain similarities and difference among nutrigenomics, nutrigenetics, pharmacogenetics, and toxicogenomics.
	Explain associated problems and challenges of transcriptomics, proteomics, and metabolomics.
	Explain the physiology of nutrition-related diseases like obesity, diabetes Type I and II, metabolic syndrome, and cancer.
	Explain the digestion, storage, and associated signaling pathways of the most important nutritional signals (micro-/macronutrients).
	Evaluate the importance of and give examples of nutrigenomics research.
	Discuss what is feasible with respect to "personalized diets" and other nutrigenomic-related topics.
Learning goal 2	After studying the learning material, the student must be able to develop feasible experiments to study nutrigenomics research questions using molecular tools/techniques (within time and money constraints).
Objectives	After studying the learning material, the student must be able to do the following:
	Formulate meaningful research questions (and hypotheses) for a nutrigenomics problem.
	Explain the function of nuclear receptors PPAR-α, PPAR-β, PPAR-γ, RXR/RAR, RXR, LXR, SREBP-γ, and SREBP-2.
	Choose, from a set of tools and techniques, the relevant tools and techniques for an experiment to answer a specific research question.
	Interpret and critically discuss the results of microarray experiments.
Learning task 1	Give arguments of whether you think that personalized diets are something nutrigenomics research will bring or whether they are just science fiction.
Part task 1	Discuss whether commercially available personalized diet advice is indeed personal (by comparing them with dietary guidelines, separately for macro-and micronutrients).
Supportive information	Nature of commercially available personalized diets
	Examples of macro- and miconutrients.
Part task 2	Discuss whether screening for <25 single-nucleotide polymorphisms is sufficient to give diet advice.
Supportive information	Metabolic pathways in which the genes for MTHFR, PPAR-γ, GSTMI, IL-6, VDR, and ApoC3 are involved.
	Roles of these genes in health and disease.
Part task 3	Give opinions about the role of nutrigenomics in the development of personalized diets (what is feasible and what is not).
Supportive information	Goals and strategies in nutrigenomics research.
	Definitions of transcriptomics, proteonomics, and metabolomics.
Formally redundant information	Students have to understand the following concepts: single-nucleotide polymorphisms, transcription factors, and gene transcription and translation.
	Students have to know the functions of the most important nutrients as well as the foods that contain these nutrients.
	Students have 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 task 1	Formulate research questions and hypotheses.
Supportive information	Information about the physiology of obesity, fatty acids, and gene transcription in the liver.
Part task 2	Design an experiment by selecting study objects, experimental treatments, and tools and techniques.
Supportive information	Information about transgenic animals and methods to measure the transcriptome, proteonome, etc.
Part task 3	Interpret the results of the experiment
Supportive information	Experimental results and information about microarray experiments.
Formally redundant information	Students have to understand the following concepts: obesity (body mass index), transcription factors. Northern and Southern blots, PCR, etc.
Procedural information	Students have to be able to search databases of the National Center for Biotechnology Information.
	Students have to be able to find information about, e.g., transgenic animals (using the website of the Jackson Laboratory) and microarrays (using the website of Affymetrix).

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

learning goal, this knowledge was 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 attention-revelance-confidence-satisfaction (ARCS) model of Keller (6), 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 were the 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 consisted 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 was "personalized diets." In this case, personalized diet means a dietary advice specifically tailored to a person's individual need as determined by his/her 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 behavior, when coupled with major technological advances in genetic screening, will drive a completely novel approach toward 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 discovered what is feasible given the state of the art in nutrigenomics and what can be expected in the future with regard to personalized diets.

The topic of the second case was obesity. According to the World Health Organization, obesity has reached epidemic proportions globally, with >1 billion adults overweight (and at least 300 million of them clinically obese) and is a major contributor to the global burden of chronic disease and disability (16). Therefore, obesity is a relevant topic for students to focus on. To motivate the student, s/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 designed and analyzed an authentic nutrigenomics experiment. While performing this experiment in the laboratory would be expensive and would require advanced laboratory skills, this case gave the student the opportunity to develop competencies in planning and analyzing a nutrigenomics experiment without extensive laboratory experience.

Structuring of Task Practice

To identify and structure learning tasks for the digital learning material, the four-component instructional design (4C/ID) model of van Merriënboer was used (13, 14). The 4C/ID model offers a structured design approach for complex cognitive skills. The four components of instructional design that are distinguished by the 4C/ID model are as follows: whole-task practice, part-task practice, supportive information (information that teacher typically calls "the theory" and that is often presented in study books and lectures), and procedural information (15). Each component will be further addressed below.

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* was to provide arguments in support of or against the concept of personalized diets. The learning task for *case 2* was to design a nutrigenomics experiment addressing the role of free fatty acids in the regulation of gene transcription in the liver (to understand more about the etiology of obesity).

These learning tasks covered the complex cognitive skills that student needs to acquire. According to van Merriënboer, complex cognitive skills are skills that 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 (13). 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 were 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 (11), 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 shows 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 were 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 was to "use just-in-time information presentation" (*guideline 3*). In brief, just-in-time information presentation means providing the student with the necessary information needed at that moment for performing a task (7, 14, 15). According to van Merriënboer and Kester, two information types can be distinguished: 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 nonrecurrent 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 (>⅓) 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 *cases 1* and *2* the learning (part) tasks together with some examples of supportive and procedural information and an example of formally redundant information.

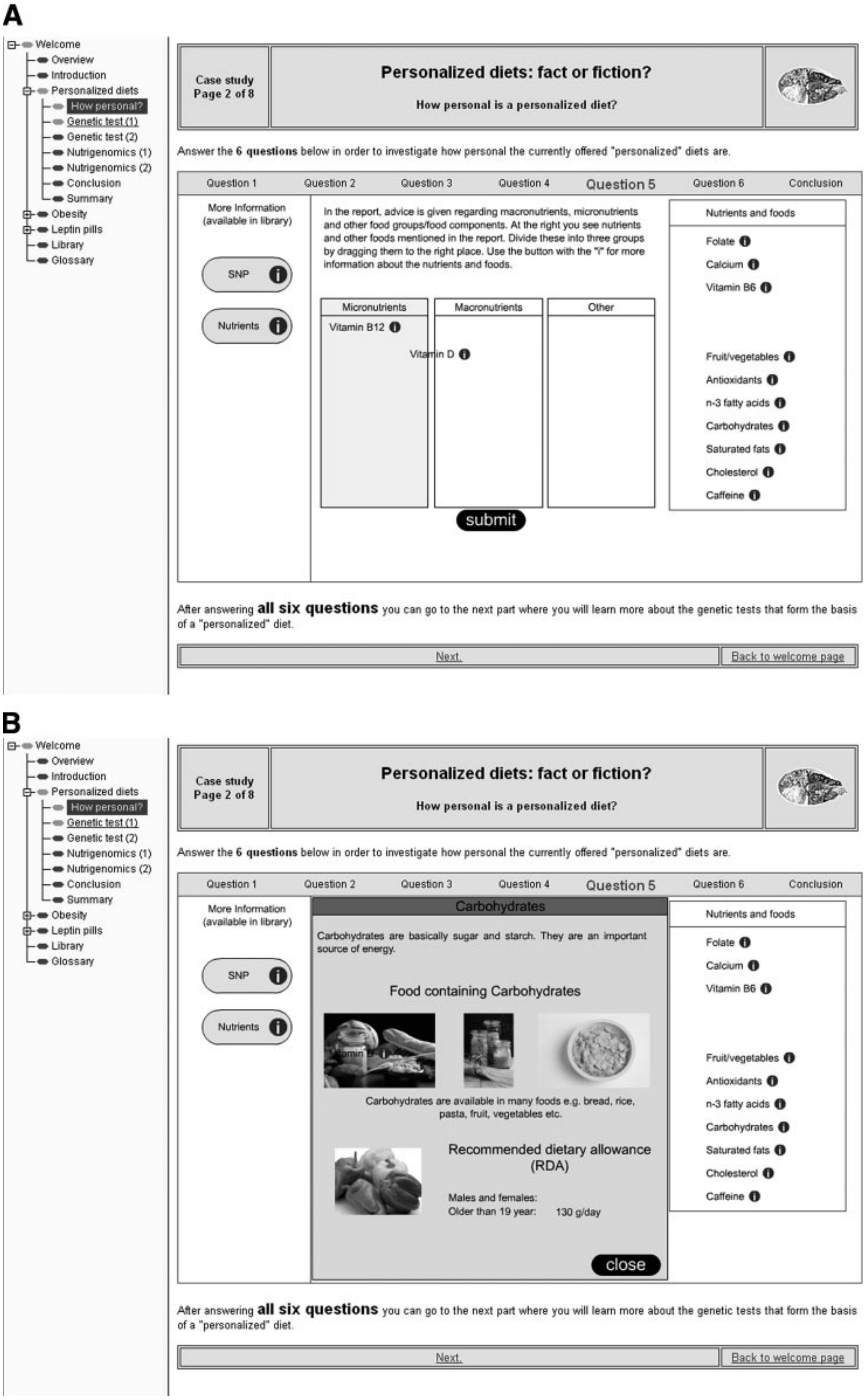
Choosing Human-Computer Interactions

Active learning is necessary for the understanding, acquisition, and retention of knowledge (1). Furthermore, practice is believed to strengthen understanding (12). 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. The following guidelines were developed for the chosen human-computer interactions.

Guideline 1: start each case with an interaction that aims at gaining the attention of the student. Several interactions are suitable for this purpose (see Fig. 1). For example, in the first case, the student had to visit some companies on the internet that claim to give "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 2: To assist the student in studying information supportive for the learning (part) tasks, use interactions that contain a low degree of freedom and that 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 actively 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.

Guideline 3: 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 (Fig. 2).



Personalized diets: fact or fiction?

How personal is a personalized diet?

Answer the **6 questions** below in order to investigate how personal the currently offered "personalized" diets are.

In the report, advice is given regarding macronutrients, micronutrients and other food groups/food components. At the right you see nutrients and other foods mentioned in the report. Divide these into three groups by dragging them to the right place. Use the button with the "i" for more information about the nutrients and foods.

After answering **all six questions** you can go to the next part where you will learn more about the genetic tests that form the basis of a "personalized" diet.

Personalized diets: fact or fiction?

How personal is a personalized diet?

Answer the **6 questions** below in order to investigate how personal the currently offered "personalized" diets are.

Carbohydrates are basically sugar and starch. They are an important source of energy.

Food containing Carbohydrates

Carbohydrates are available in many foods e.g. bread, rice, pasta, fruit, vegetables etc.

Recommended dietary allowance (RDA)

Males and females:
Older than 19 year: 130 g/day

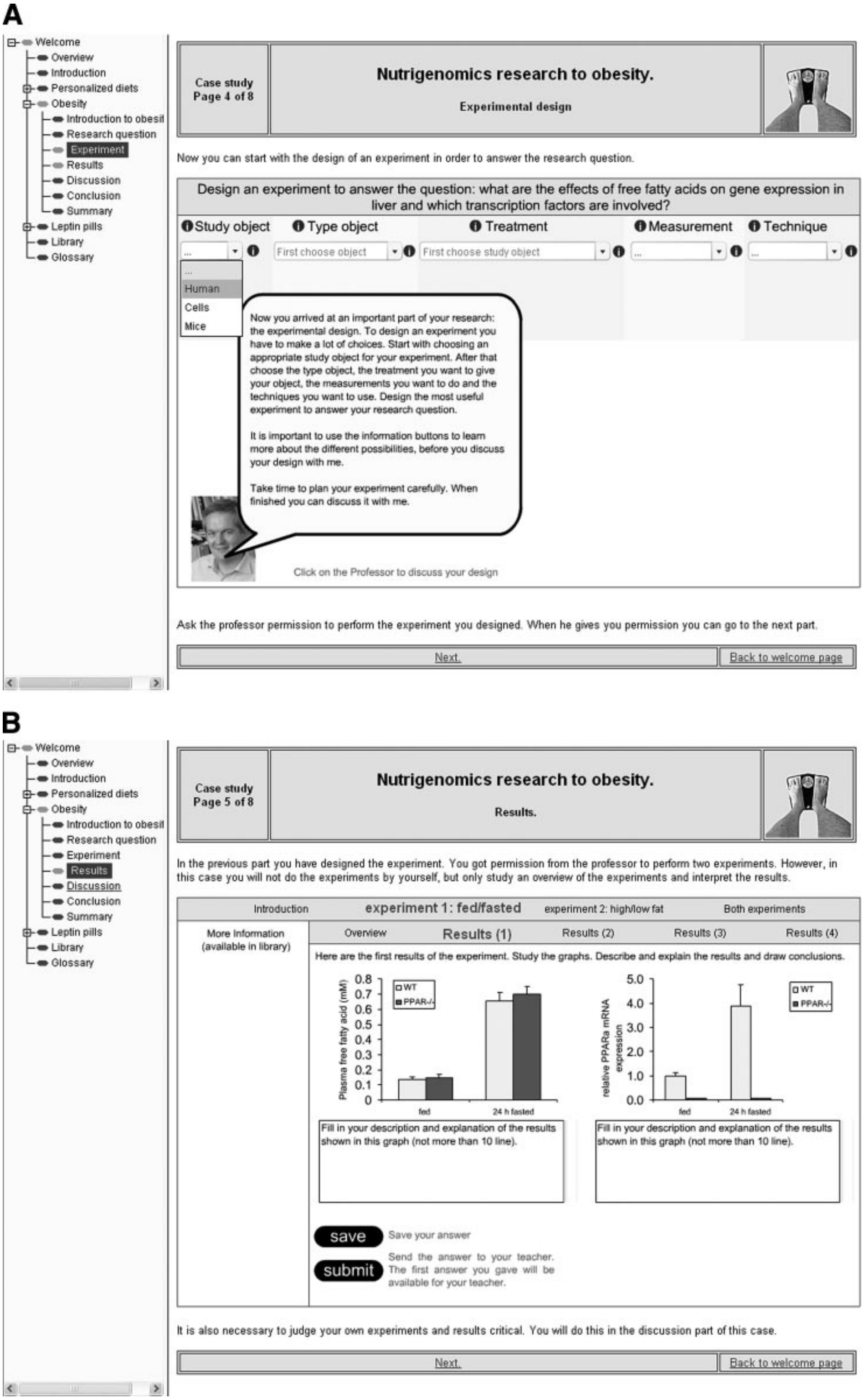
After answering **all six questions** you can go to the next part where you will learn more about the genetic tests that form the basis of a "personalized" diet.

Fig. 1. 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 following learning part task: "find out whether the personalized diet offered is really personal?" (*case 1*). *B*: information regarding specific nutrients. This was just-in-time information to the student while they performed the interaction shown in *A*.

Guideline 4: 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 (Fig. 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 were implemented because it is information with a low intrinsic complexity and practicing with this information automatically occurs



Nutrigenomics research to obesity.

Experimental design

Now you can start with the design of an experiment in order to answer the research question.

Design an experiment to answer the question: what are the effects of free fatty acids on gene expression in liver and which transcription factors are involved?

Study object	Type object	Treatment	Measurement	Technique
...	First choose object	First choose study object	...	...

Now you arrived at an important part of your research: the experimental design. To design an experiment you have to make a lot of choices. Start with choosing an appropriate study object for your experiment. After that choose the type object, the treatment you want to give your object, the measurements you want to do and the techniques you want to use. Design the most useful experiment to answer your research question.

It is important to use the information buttons to learn more about the different possibilities, before you discuss your design with me.

Take time to plan your experiment carefully. When finished you can discuss it with me.

Click on the Professor to discuss your design

Ask the professor permission to perform the experiment you designed. When he gives you permission you can go to the next part.

Nutrigenomics research to obesity.

Results.

In the previous part you have designed the experiment. You got permission from the professor to perform two experiments. However, in this case you will not do the experiments by yourself, but only study an overview of the experiments and interpret the results.

Here are the first results of the experiment. Study the graphs. Describe and explain the results and draw conclusions.

Fill in your description and explanation of the results shown in this graph (not more than 10 line).

Fill in your description and explanation of the results shown in this graph (not more than 10 line).

Save your answer

Send the answer to your teacher. The first answer you gave will be available for your teacher.

It is also necessary to judge your own experiments and results critical. You will do this in the discussion part of this case.

Fig. 2. Interaction type to perform a part task. *A*: interaction type to perform the part task of "design an experiment" (*case 2*). In this interaction type, the student can design an experiment by choosing from >100 possible combinations of study objects, treatments, measurements, etc. *B*: free format question to perform the learning part task of "interpret the results from your experiment" (*case 2*).

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 were implemented. This information is presented during the learning task in small parts (with minimal intrinsic complexity) that 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 Fig. 1*B*).

For the presentation of information, an important guideline was 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 (9). Mayer (9) stated 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." Furthermore, Larkin and Simon (8) and Sweller et al. (12) suggested that, when well-designed images or diagrams accompany text, understanding and retention of knowledge generally improves. Figure 3 gives an example of an animation used in the learning material.

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

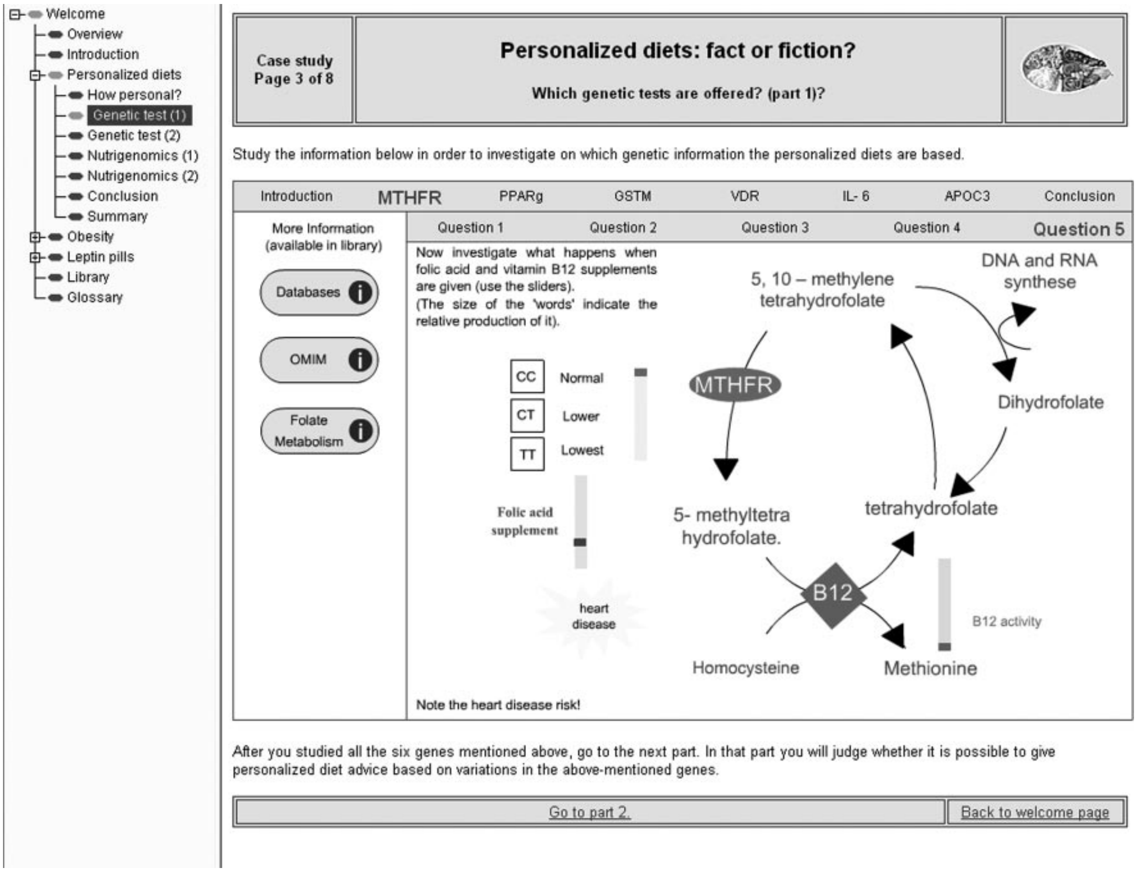
Assumption for the Use of the Learning Material

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 were 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 were 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 article to describe all these assumptions in detail.

Evaluation of the Learning Material

For the evaluation of the learning material, three types of evaluations were applied: *1*) an evaluation in which students, within a certain educational setting, evaluated the learning material; *2*) an evaluation based on the exam results of students; and *3*) an evaluation in which one or more (independent) experts in nutrigenomics or related fields evaluated the learning material. The purpose of these evaluations was to test whether the design satisfied (specific) requirements. Besides this, the evaluations provided arguments to adjust the learning material.

For the first evaluation of the learning material, all three evaluation types were applied. During an 8-wk 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 5-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 5-point Likert scale. After this first evaluation, some limited adjustments to the learning material were done as recommended by the expert.



Case study
Page 3 of 8

Personalized diets: fact or fiction?

Which genetic tests are offered? (part 1)?

Study the information below in order to investigate on which genetic information the personalized diets are based.

Now investigate what happens when folic acid and vitamin B12 supplements are given (use the sliders). (The size of the 'words' indicate the relative production of it).

Note the heart disease risk!

After you studied all the six genes mentioned above, go to the next part. In that part you will judge whether it is possible to give personalized diet advice based on variations in the above-mentioned genes.

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

Table 3. *Results of the evaluation in an educational setting*

Requirement	First evaluation (n = 22)		Second evaluation (n = 15)	
	Case 1	*Case 2*	*Case 1*	*Case 2*
Mean (% students with a score of ≤6)				
R1A. Exam results (10-point scale)	8.3 (10)	7.5 (38)	6.8 (32)	6.1 (47)
Mean (% 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 were 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 knew.	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 (where *1* was poor and *5* was excellent).	4.0 (90)	4.2 (95)	3.7 (67)	4.1 (92)

Note that *requirements R2, R4,* and *R5* were only evaluated during the second evaluation.

The second evaluation was performed in the same course, 1 yr 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 out an evaluation form consisting of agree-disagree questions on a 5-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's program in nutrition and health, the master's program in biotechnology, the bachelor's program in biotechnology, and the bachelor's program in nutrition and health and from outside Wageningen, following an exchange program (22 students in total). It took students 8–12 h to study each case once. Most students studied the learning material again, at home, in preparation for the exam. To study each case in depth took 16–24 h (∼0.75–1 credit in the ECTS). Besides the digital learning material, the course contained lectures related to other nutrigenomics topics and a small laboratory portion. Students studied the digital learning material in scheduled computer rooms. Table 3 shows an overview of the evaluation results and demonstrates that the students enjoyed studying the cases and perceived to have learned much from them. 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 exercises in the cases were clear and understandable, indicates that the learning material was suitable for a target group heterogeneous with respect to prior knowledge.

During this first evaluation, the exam results of the students were analyzed. The exam consisted of 12 essay questions, of which ∼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 10-point scale).

During this first evaluation, an independent expert also evaluated the learning material. Table 4 summarizes the results of the expert evaluations. In general, the expert confirmed that the scientific information was sufficient and that 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, the addition of information, and some small changes in the 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, 1 yr later. Nineteen students followed this course, of which 15 students completed the evaluation form. Again, from this evaluation, it appeared that most design requirements were fulfilled, although the students

Table 4. *Results of the expert evaluation*

Requirements	*Expert 1* (rating all cases)	*Expert 2* (rating *case 1*/*case 2*)	*Expert 3* (rating *case 1*/*case 2*)
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

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 students 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 2 subsequent years, the evaluations are not completely comparable. For example, the courses differred 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's program in nutrition and health and fewer were from the master's programs in molecular biology or biotechnology; therefore, it is reasonable to expect that the students differed 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 out 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 (*requirements R5B*, *R9*, and *R10*).

Conclusions

The main challenges for the design of digital learning material that introduces students to the field of nutrigenomics were the formulation of learning goals and objectives, the identification of topics, and the implementation of helpful learning tasks. Another challenge was to formulate new guidelines [in addition to the guidelines described previously (3, 4)], 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 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 that differ more or less from the field of nutrigenomics.

From the 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, the first attempt to use the learning material within other educational settings was 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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