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ABSTRACT

An important learning goal of a molecular biology curriculum is a certain proficiency level in experimental design. Currently students are confronted with experimental approaches in textbooks, in lectures and in the laboratory. However, most students do not reach a satisfactory level of competence in the design of experimental approaches. This paper describes the development of a Web-based application that supports the learning of this design skill. The application consists of an activating part and a library part. In the activating part, the student is presented with a biological question that must be solved experimentally. Therefore, the student has to make a set of coherent choices, execute steps in an experiment and interpret the experimental results. Furthermore, a DNA sequence has to be analyzed with Web-based databases. The library consists of learning objects that present essential background information. A test with a small group of students yielded very promising results. (Author)

Web Based Learning Support for Experimental Design in Molecular Biology

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Abstract: An important learning goal of a molecular biology curriculum is a certain proficiency level in experimental design. Currently students are confronted with experimental approaches in textbooks, in lectures and in the laboratory. However most students do not reach a satisfactory level of competence in the design of experimental approaches. This paper describes the development of a web-based application, which supports the learning of this design skill. The application consists of an activating part and a library part. In the activating part, the student is presented with a biological question that must be solved experimentally. Therefore, the student has to make a set of coherent choices, execute steps in an experiment and interpret the experimental results. Furthermore, a DNA sequence has to be analyzed with web-based databases. The library consists of learning objects that present essential background information. A test with a small group of students yielded very promising results.

Introduction

The Food and Biotechnology (FBT) program aims at the creation of a rich body of digital learning material for university curricula related to food science and biotechnology. The FBT program was initiated at Wageningen University in September 2000. The program focuses on web based learning support for those learning goals where digital learning material is expected to have a clear added value. One of the FBT projects aims at the development of digital learning material for molecular biology. This paper describes the first stage of this project.

One of the important learning goals of a molecular biology curriculum is a certain proficiency level in designing an experimental approach. This involves the application of different techniques. Students are usually capable of understanding how these different techniques work, but they have difficulty in combining them in a useful way and in judging whether they are suitable to find an answer to a particular question. Moreover, students often do not realize that experiments are performed with biological systems. Consequently they do not use their knowledge of biology when designing experimental approaches, even though this is essential for the design of a useful approach. This lack of applying biological knowledge can also be observed during the analysis of experimental outcomes.

The indicated problems in experimental design may be inherent in the current educational setting. Currently students are confronted with experimental approaches in textbooks, in lectures and in laboratory courses. Each of these formats has its own drawbacks. Textbooks do describe many experiments and approaches, but this is not sufficient for students to learn to choose techniques and to schedule operations. One of the problems is that students usually focus on the mechanisms behind techniques, thereby losing sight of the uses of such techniques. In a lecture, more weight can be put on the actual designing of experimental approaches. It is however very hard to involve more than a limited number of students individually in such a way. Furthermore, the students that do get involved, can hardly get personal feedback due to considerations the lecturer has to take of the other students as well as the time allotted for the lecture. In a laboratory course finally, students have little freedom in choosing and scheduling operations. Moreover, they become preoccupied with the practical skills they still lack, such that the overview of even the specific experimental approach is lost. Thus the teaching of more general aspects of designing experiments is practically impossible. The possibilities of computer based learning support may offer a solution to the above problem. Apart from the well known argument that computer based learning support makes it possible to activate each student individually and generate personal feedback, many of the experimental results in molecular biology experiments are photographs or sequences and can thus be represented digitally. Moreover, the processing of results in molecular biology experiments requires computers and web access. Recently, many DNA and protein sequences have become available in web-based databases. In current molecular biology research, using these databases becomes increasingly important for the design of experimental approaches and the interpretation of experimental outcomes. Therefore, learning to use information from databases was added as new learning goal to an undergraduate course. For an effective use of the available data, database searches have to be performed and the data have to be integrated with biological knowledge and knowledge about molecular biology techniques.

Thus web-based learning support should improve the following skills:

- designing a basic experimental approach by selecting and combining suitable techniques;
- performing a database search;
- integrating information from biology, techniques and database searches.

These skills can only be improved when sufficient background knowledge can be used. Knowledge that the students have not mastered yet, has to be presented as well.

The material has to complement the lectures. As the lectures may change from time to time, the material should consist of modules that can be combined flexibly. It should also be possible to use these modules independently from the lectures.

In this paper we describe the development of the first module including the results of a first evaluation. The paper finishes with a discussion of the methods we applied to teach the skills mentioned above.

The Global Structure of the Site

To offer students the opportunity to practice the necessary skills, they are offered a case (see demo site) in which they have to design an experimental approach to solve a real (but basic) biological problem. Thereby the theory is placed in the proper context. This may be favorable for retrieving the theory from memory in a similar context (Anderson 2000), but this also makes its relevance more apparent, which may motivate students (Keller 1987). The background information that is needed to successfully go through the case is available to the students just when they need it. This just-in-time information presentation is, among others, recommended by the Four Component Instructional Design model (van Merriënboer 1997), which gives guidelines for teaching complex cognitive skills. Some background information may be needed several times, when going through the case. To be able to offer this information from one place, we constructed a library (see demo site) that contains all necessary background information. This library consists of independent self-explanatory learning objects. Because of this setup, it is possible to study only a selection of the learning objects and no specific study order is required. In case a student prefers this, he could also study all background information before starting with the case. The library also ensures that students with varying amounts of prior knowledge can in principle complete the case.

The Light Induction Case

In the light induction case the student has to isolate a gene that is induced in plants upon light exposure and analyze its DNA sequence. The student is guided through the case by multiple-choice questions to prevent him from getting lost and frustrated. Sometimes a choice between different techniques is offered. In this way the student is stimulated to actively think about the possibilities of the techniques, which is essential for the design of an experimental approach.

After choosing a technique, the student is immediately confronted with the experimental result. This result has to be interpreted in order to find out whether applying the technique was indeed useful. Thereby it is essential to take biological aspects into account. This is illustrated by the screen dump from the demo site shown in figure 1. This shows the screen the student sees after choosing to analyze differences in mRNA concentrations on an RNA gel on which total RNA is loaded. This choice has led to a useless result because mRNA cannot be visualized with this method. This is partly due to the fact that mRNA, the RNA that needs to be studied, forms only a minor fraction of total RNA. Thus, it is necessary to use knowledge about biology to decide whether the technique is useful. The student will discover that the technique was not useful after selecting a band for analysis.

This format in which students are confronted with a result that they have to interpret has several advantages. Firstly, students probably remember better whether a technique is useful in a certain context when they discovered this themselves than when this would have been told. Secondly, if students do not use their biological knowledge, they are confronted with the consequence. This probably makes a stronger impression than when this is pointed out during a lecture. Thirdly, a picture of an experimental result contains implicitly much information about the precise use of a technique. By interpreting the results, students are stimulated to focus on and give meaning to these results. These include results of techniques that were not useful and that are usually not shown in a textbook. As people tend to have good memory for meaningful interpretations of an image (Anderson 2000) and easily make inferences from them (Larkin *et al.* 1987), the students are in this way again stimulated to remember the precise use of a technique.

Sometimes it is also necessary to interpret the result in order to continue with the procedure.

The gene can eventually be obtained by applying a method that is called "differential screening". This method was chosen for several reasons. Firstly, the problem is an example of a very common research question in molecular biology. In many instances, genes that are specifically induced under certain conditions have to be identified. Even though differential screening is a relatively old method it was chosen because it clearly illustrates the problems involved. Moreover, more advanced methods are still largely based upon the same principles. Therefore, understanding the differential screening method may facilitate the understanding and proper application of technologically more advanced methods, based on an analogy process (Anderson 2000).

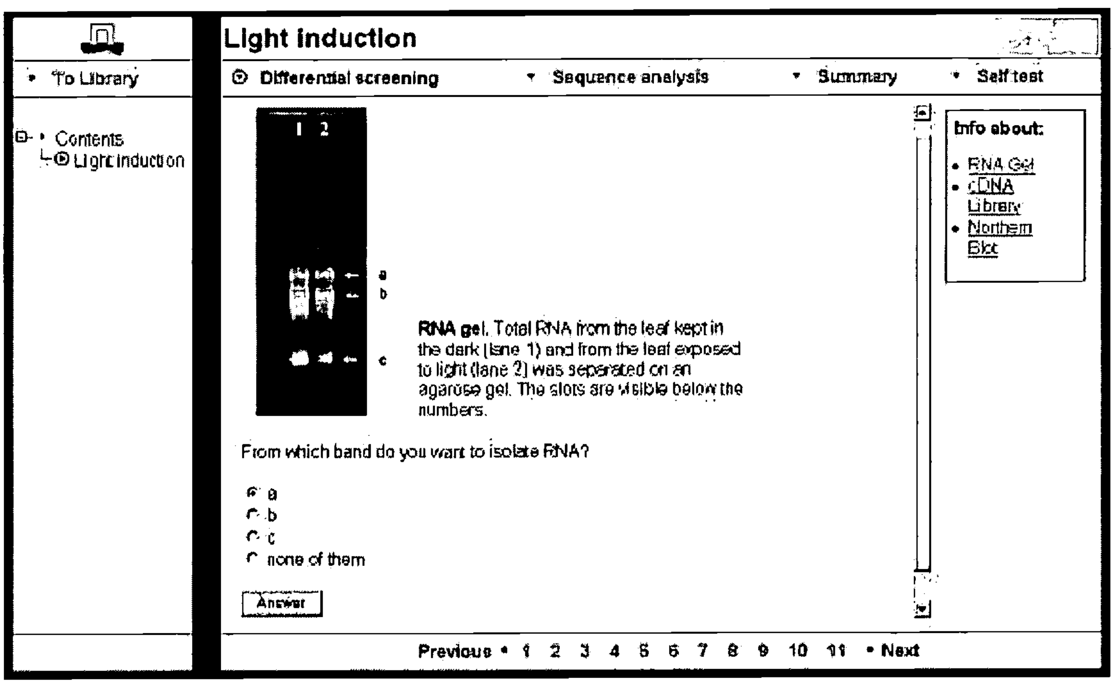

Figure 1. Screen dump of a screen a student see after selecting a technique. To be able to interpret this result, the student needs to use biological knowledge. Only after interpreting the result correctly, it becomes clear that this technique was not useful in this context.

After isolating the desired gene, the DNA sequence of the gene has to be analyzed (see sequence analysis section at the demo site). The first sequence to be analyzed is not complete, as is usually the case in practice. Another reason why this partial sequence is offered is that the student has to discover for himself that it is not complete. Therefore, experimental findings have to be combined with knowledge from biology. The student has to perform an additional experiment to obtain the complete sequence. This sequence has to be analyzed by performing a database search. To perform this search it is again necessary to actively use biology knowledge as well as knowledge about the applied experimental techniques.
The interactive part of the case is followed by a summary. This summary contains overview pictures as well as information about why applying a technique in the given context was useful or not. The summary contains in principle all necessary theoretical information. Thus, the interactive part should support the training of extra skills, whereas the theory can be found in the summary.
Finally, a number of multiple-choice questions are implemented which serve as a self-test.

The Library

The library contains background information that is necessary to go through the case, so that the material can in principle be used by students with varying amounts of prior knowledge. The library contains information about techniques, database searches and processes that take place inside cells. As mentioned before the library contains independent and self-explanatory learning objects.
The explanation of a technique consists of 2 to 6 movies, because of our positive previous experiences with these types of movies. Figure 2 gives a screen dump (see demo site) of the introduction page for the technique, which is labeled DNA gel. The page contains pictures that give an impression of the content of the movie. The student can click on a picture in order to start a movie. The movies do not take more than 2 minutes. They consist of spoken text supported by photographs, annotations and animations. As stated before, it is essential for designing experimental approaches to know the different purposes of a technique. Therefore, this is stressed in the first movie. The second movie explains the principle of a technique.

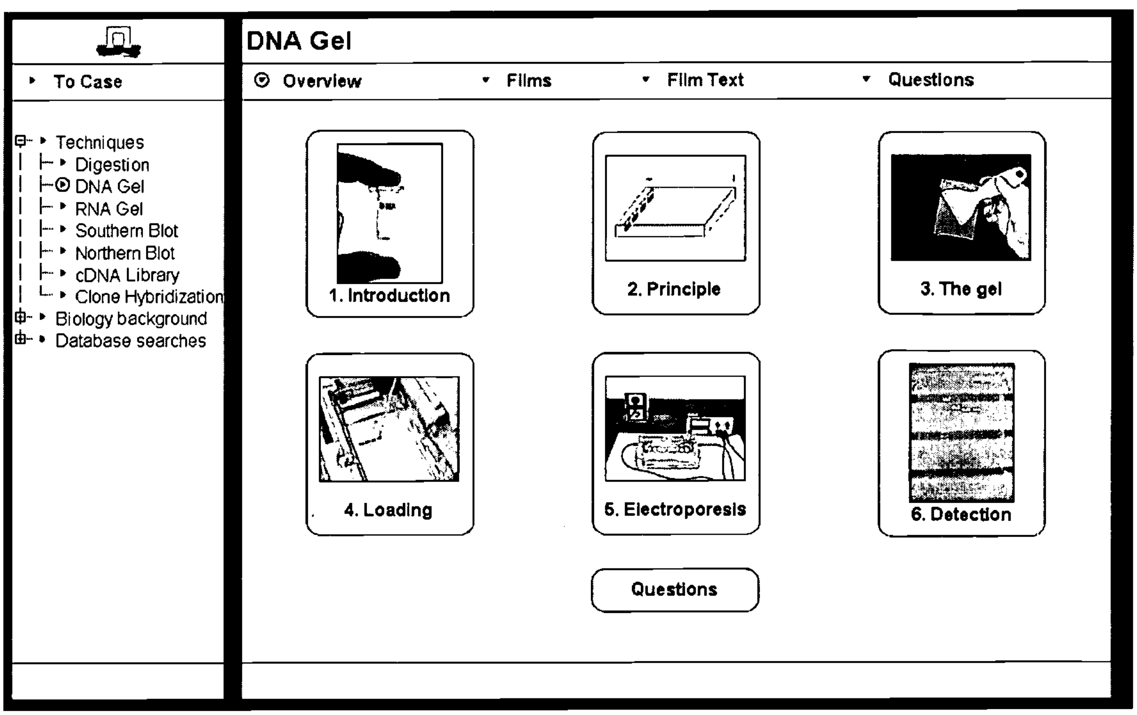

Figure 2. Typical introductory screen for a technique in the library. Pictures give an impression of the content of the movies. A student can click on a picture to start a movie. Questions are available as well.

The explanation of some techniques also highlights specific steps of the technique to give the student an idea of its complexity and scale. A movie showing a typical experimental result is sometimes added as well, which makes it easier for the student to interpret results himself later on. The written text and the still images of each movie are available. Extensive experience with the use of movies at Wageningen University has shown that some students prefer to view the text when the pace of the movie is too slow for them. The written text is also better for students who just want to scan through the theory quickly (Hartog *et al.* 2000), for students whose mastery of the English language is insufficient to understand the audio and in situations when there is no sound available. Beside the movies, each learning object contains a couple of short questions to let the student internalize the newly acquired concepts. In case of similar techniques, movies that explain identical steps, are actually identical. If applicable, this is clearly indicated.
The learning object on the database search contains some text to explain the background and a simple simulation. In this simulation a search can be performed in controlled circumstances. When the student follows the instructions given on top of a page, he stays within the simulation and gets new instructions. It is however also possible to leave the simulation and find out what happens when another strategy is followed. This learning object also contains some multiple-choice questions.
The learning objects dealing with the biology background contain schematic drawings, tables etc. in which the most important information is summarized. These objects serve to refresh the student's memory and are not meant to teach them new information.

Evaluation Results

So far the material was evaluated with a group of 6 volunteers. This evaluation was carried out to identify ways to improve the site. By testing the site with a small number of users, most usability problems should become clear (Nielsen, 2000). The students first had to give an indication of their prior experiences and they had to make a short test. Next, the students worked in pairs through the site. Finally they performed a post-test that was similar to the first one and completed an evaluation form. The students judged the site on average with an 8.7 on a scale of 1 to 10. Thus, the students were very enthusiastic. Reactions on the evaluation forms include:

- "The overall impression is very positive. By performing a virtual experiment you become able to understand techniques, but more important, learn to combine different techniques to come to a good result."
- "I think it is a good idea showing some films because this helps to imagine the practical work and not only the theoretical explanation. And then, the possibility of listening the explanation is very appropriate because, in this way, it is not so tiring reading the whole text from the computer screen."

The evaluation also yielded ideas for improvement. Most importantly, students had problems to perform the database search. Therefore, the above mentioned simulation was added to the library. Further minor improvements include the addition of a clarifying figure, the reformulation of some feedback and the removal of a number of spelling mistakes.
An important test result is, that each student applied the concept of differential screening sufficiently well after studying the material whereas only one student already managed to apply this concept before studying the material. Furthermore, in the post test the students had to design an approach to solve a (basic) biological problem that was different from the problem they solved at the site and that required a different approach to be solved. The students performed better in the second test than in the first test, even though the problem was slightly more difficult. Overall, the results were encouraging.

Final Remarks

A web based application, which supports learning experimental design in molecular biology has been developed. The web site has been evaluated by a small group of volunteers. Currently the demo site is accessible worldwide for review. The site will be used in Wageningen in the course "gene technology" in spring 2002.
The ultimate goal will be that students can design experimental approaches in new, unfamiliar situations. The application confronts the students with situations and experimental results, which force them to actively use their knowledge of biology while designing a new approach. It is expected that applying their knowledge,

while working with molecular biology techniques will eventually become habitual.
The web site teaches to design an experimental approach addressing a new question in molecular biology in three ways. Firstly, the differential screening method that students use in the case, can be used to address similar biological questions. Secondly, the differential screening method can also serve as a schema when designing an analogous, technically more advanced approach. Finally, the application forces the student to focus on the precise use of each technique in multiple ways. It is essential that the student becomes very much aware of what the use of a technique exactly is. Thus, it should become easier to design new approaches using the same techniques. Moreover, students will probably gradually learn to focus more on the use of a technique when studying new ones in the future. This may even lead to a better performance for designing approaches that consist of these new techniques as well.
Currently, several additional cases are being developed, covering the production of transgenic organisms. The research is progressing towards a qualitative simulation environment that will present the consequences of a student's choice in terms of experimental results based on programmed rules. The number of different options will be almost unlimited in the perception of the student. On the one hand this offers the students a more realistic situation and more opportunities to test their own ideas, but on the other hand students could easily flounder and show unstructured behavior (de Jong *et al.* 1998). The main challenge for the future will thus be to embed the simulation of experiments in an environment that guides and supports the students.

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