Adaptive e-learning for biotechnology

(how) does it work?

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Janneke R. van Seters

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Abbreviations

CBLE	Computer-Based Learning Environment
CGKT	Cell Growth Kinetics Tutor
EKT	Enzyme Kinetics Tutor
FP	Feedback about the Processing of the task
FR	Feedback about self-Regulation
FS	Feedback about the Self as a person
FT	Feedback about the Task
M	Mean
Mdn	Median
PCR	Polymerase Chain Reaction
SD	Standard Deviation
SRL	Self-Regulated Learning

Glossary

Terms that are explained in this glossary are underlined at their first occurrence in each chapter: glossary-term.

Adaptive e-learning: Adaptive e-learning is generally perceived from the instruction point of view and comprises computer-based learning systems that can interact with a student to provide the most appropriate instruction.

Adaptive e-learning material: Learning material that can adapt to the student by varying the content that is presented based on individual student characteristics.

Adaptive feedback: Feedback that can provide tailored instructions by varying its content according to a student's individual characteristics and performance.

Authoring tool: Computer based system that allows non-programmers to create content for an intelligent tutoring system.

Cohort: One group of students.

Computerized adaptive test: A form of computer-based test that adapts to the examinee's ability [1].

Constructivism: A learning theory that states that students generate knowledge and understanding built on their own experiences and ideas

Content model: The component of an intelligent tutoring system that contains the concepts that a student has to master.

Distance learning: Distance learning or education describes teaching-learning relationships where the actors are geographically separated and communication between them is through technologies such as audio and video broadcasts, teleconferences and recordings; printed study guides; and multimedia systems. (as defined by the American Journal of Distance Education)

Domain model: See content model.

E-learning: Learning that takes place in front of a computer that is connected to the Internet [2].

Embedded direct intervention: An instruction that is integrated in the learning environment and thus forces students to consider it.

Engine: In computer science, a software engine refers to the core of a computer program. Software engines drive the functionality of the program, and are separate from other aspects of the program, such as look and feel.

Feedback: Any message that is generated in response to a student's action [3].

General hint: Local feedback that is presented after submitting any incorrect answer.

Global feedback: General feedback that provides coaching for several aspects of the entire learning process, but does not target specific errors made by students.

Hypermedia environment: A multimedia environment in which related items of information are connected and can be presented together [4].

Intelligent tutoring system: A computer system that provides direct customized instruction or feedback, i.e. without the intervention of human beings to students who are performing a task.

Intelligent Web-based Educational System: A system that applies techniques from the field of artificial intelligence to provide, broader and better support for the users of Web-based educational systems [5].

Intervention: Interference of a scientist in a social environment to alter the circumstances. In this study, the introduction of an adaptive e-learning module in a course to study its effect is an intervention.

Learner model: The component of an intelligent tutoring system that contains information about the individual student, such as preferences for textual or visual information, demographic data such as gender or age, and information about the knowledge of a specific topic.

Learning path: In this study, the learning paths of students consist of the step sizes that a student selects, the number of tries needed to answer the subsequent exercise correctly, the number of credit points that a student obtains after finishing the exercise and the variation in step size selection with regard to the number of tries the student needed.

Local feedback: Feedback that is given in response to student activities aimed at correcting errors and guiding students in solving the problem

Metacognition: Thinking about one's thinking.

Misconception: Old term to describe an idea which is wrong because it has been based on a failure to understand a situation, now called alternative conception.

Module: The whole of learning objectives with associated exercises that is offered as an independent component during a course.

Proteus: The adaptive e-learning system to create adaptive e-learning material that is studied in this thesis.

Reliability: The consistency of a measurement, *i.e.* the degree to which an instrument measures the same data each time it is used under the same conditions with the same subjects

Self-regulated learning: A learning situation in which students set their own learning objectives. To achieve the objectives students plan, conduct, regulate and evaluate the learning process independently.

Specific feedback: Local feedback that is associated to specific incorrect answers that students enter.

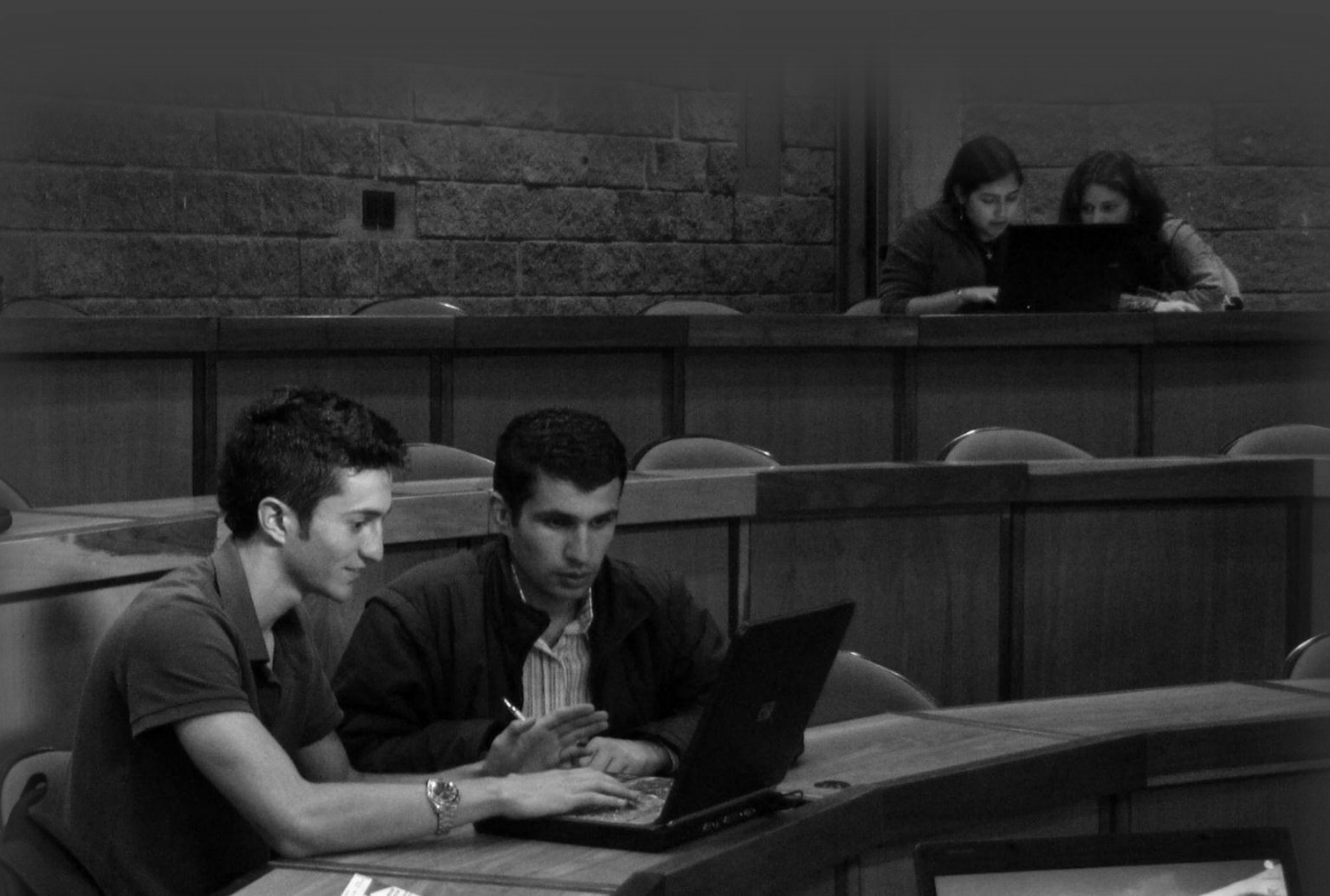
Student model: see learner model.

Trace: Observable representations of cognitive, metacognitive and motivational events [6]. In this thesis, traces are the logged interactions of students with the adaptive e-learning material.

Validity: The extent to which an instrument measures what it is supposed to measure

Part I Introduction

Chapter 1 of this introduction describes the rationale for this study on adaptive e-learning and considers the context in which it was conducted. The issues that are of specific interest to investigate adaptive e-learning material are translated into three research questions. The adaptive e-learning material under investigation was developed using the adaptive e-learning system Proteus. Chapter 2 describes the existing literature about adaptive e-learning systems. This chapter also introduces the theory of self-regulated learning and feedback, since these two concepts play are central topics in the study.



Chapter 1
Context and aim

The research described in this thesis deals with the evaluation of adaptive e-learning material for biotechnology. This chapter gives background information about the content of the learning material and the context in which the learning material was developed. Next, the context in which this research project was conducted is described together with the recent developments in academic biotechnology education. The aims to develop and evaluate the adaptive e-learning material are described and an overview of the research presented in this thesis is given.

1.1 Towards biomass-based technology

Society cannot remain dependent on oil as the main source of fuel and chemicals. Climate change, the depletion of fossil fuels and increasing oil prices call for a shift in the chemical industry from fossil feed stocks to renewable materials (i.e. biomass). New technology is needed to make the various forms of biomass suitable as feedstock. As such, we need trained scientists and engineers to develop and apply this new technology.

The shift in resources will result in a transition from an oil-based to a bio-based economy/society. The bio-based society is characterized by the conversion of biomass into fuels, chemicals, materials and energy. A new, biomass-based technology is thus needed to enable this shift in an industrially feasible way. Process steps in the chemical industry, especially in the early phases of the processes, have to be switched to their bio-based counterparts. Biomass-based technology is characterized by enzyme catalysis (biocatalysis), fermentations, downstream processing and biorefinery, in addition to traditional chemical catalysis, chemical reactions, chemical separations and purifications, and oil refinery (Figure 1 on the next page).

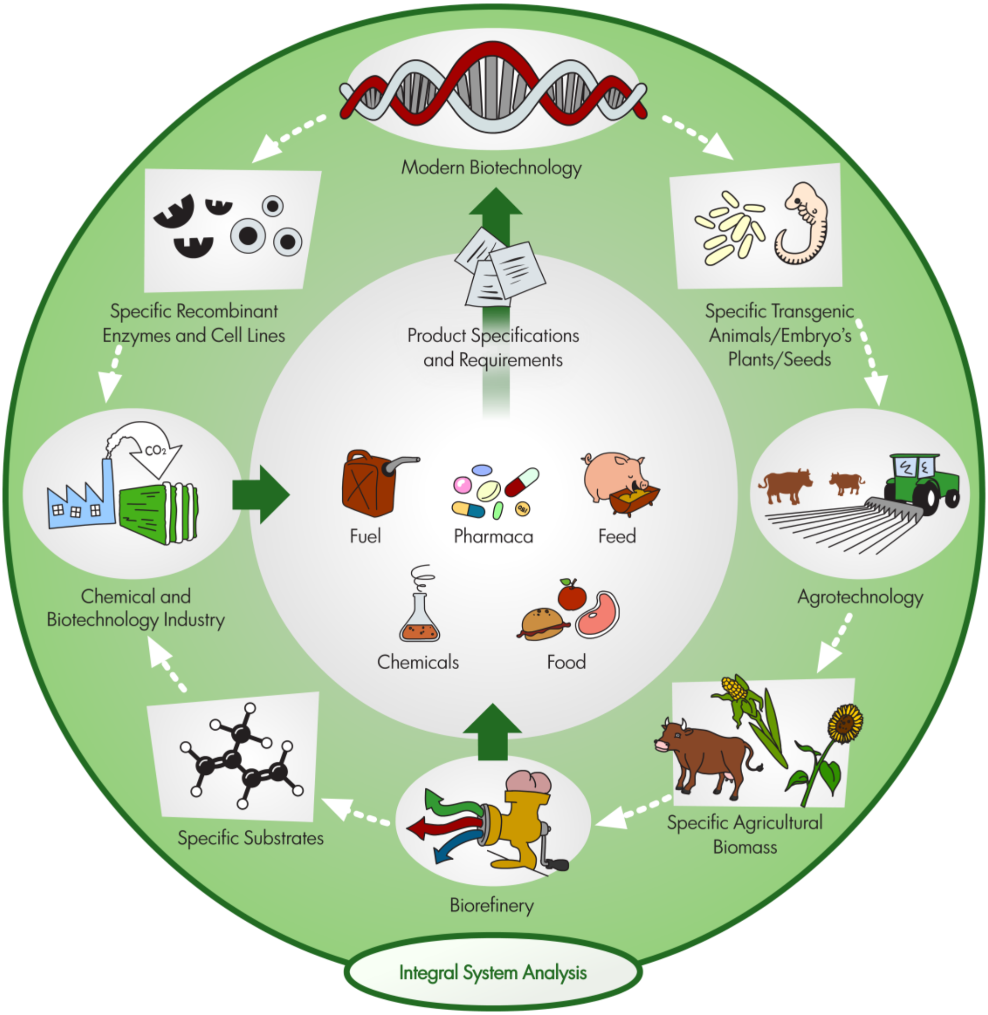


Figure 1. Simplified overview of subjects that together form the bio-based economy

The renewable feedstocks originate from specific transgenic seeds and plants or animals that are created with modern biotechnological techniques, such as genetic engineering and cloning. Growing these plants and animals requires agrotechnology, which yields specific biomass that can be refined into diverse end products. The end products should partly mimic their oil-based counterparts to avoid severely disrupting the subsequent processing. In other cases, biomass-based end products might have other, better characteristics than oil-based products, for instance increased compatibility with the human body in the case of pharmaceuticals. In addition, intermediate products can be manufactured that form substrates for other industrial production processes. The conversion of these substrates can be carried out by recombinant enzymes and cells that are again produced with modern biotechnological techniques.

The transition thus requires a paradigm shift in the study programmes of universities, namely a shift from oil-based to biomass-based technology. The role of oxygen exemplifies this shift. In many petrochemical production processes, oxygen is first inserted into highly reduced compounds, for instance in the conversion of ethylene into ethylene oxide or ethanol. In contrast, oxygen has to be removed from the mostly highly oxidized biomass-based substrates to make them suitable for further processing in the current petrochemical industry. An example is the fermentation of glucose into ethanol with CO_2 as a by-product. The latter can serve as substrate in photosynthetic cell cultures (micro-algae, cyanobacteria) to generate high-value intermediate products such as isoprene [2].

1.2 B-Basic educational program

The required shift in university study programmes from oil-based to biomass-based technology is supported by the Dutch B-Basic educational programme [3]. B-Basic (Bio-based Sustainable Industrial Chemistry) is a large public–private partnership. It operates under the auspices of the Department for Sustainable Chemical Research of the Netherlands Organization for Scientific Research (NWO-ACTS). The programme focuses on the use of new technologies from the fields of molecular biology, bioprocess technology and chemistry to achieve the bio-based production of chemicals that are more sustainable than the current oil-based technologies. The research programme incorporates an education component that is intended to facilitate, optimize, guarantee and anchor the generation and dissemination of biotechnological knowledge and competences. To achieve this, various teaching materials and activities have been developed, for example courses, readers, adaptive e-learning material [4, 5] and a practical [6]. This thesis focuses on adaptive e-learning material. This material builds on an education development programme of Wageningen University: the Food and Biotechnology (FBT) programme. The FBT programme, which started in September 2000, is aimed at the creation of a rich body of e-learning related to food science and biotechnology for university study programmes. Five PhD theses have been written within the framework of the FBT programme [7-11]. These theses describe the design of e-learning material, which is now used in many courses at Wageningen University. The material has also been implemented in courses at universities in Lausanne (Switzerland), Medellin (Colombia) and Barcelona (Spain).

1.3 Recent developments in academic biotechnology education

Recent developments in higher biotechnology education have led to an increased heterogeneity of the student population. Student mobility has increased due to the introduction in the EU of the Bachelor/Master system. This increase has resulted in a diverse inflow of Master's students. Unlike in the past, Master's students may now follow different Bachelor's programmes before they enter the Master's programme. This difference in prior education implies that not all students have the pertinent knowledge needed for the Master's course they take. The increased heterogeneity of student populations requires an educational method that is different from the one applied when incoming students have been similarly prepared.

In biotechnology education, the general increase in the heterogeneity of the student population is even higher due to the lack of biotechnology study programmes in some countries. Universities in Europe and the United States have set up study programmes in applied life sciences – such as biotechnology, biochemical engineering, and life science and technology – while the life science programmes in other countries lack the engineering component, or their engineering programmes do not include biological courses. The absence of biotechnology study programmes in these countries has led to an increased inflow of biotechnology students into Master's programmes abroad. It is very important to train these and other students, since the demand for biotechnologists is continually increasing and can be expected to increase even more in the near future.

1.4 Personalized education with adaptive e-learning material

Students from different countries who embark on a biotechnology Master's programme do not share the same background. Their prior knowledge and learning strategies vary, and this calls for personalized teaching. One way to achieve personalization is to use adaptive e-learning material [12]. Adaptive e-learning material has been implemented in a range of disciplines, for example foreign languages and literature [13, 14], medical sciences [15, 16] and computer programming [17]. Adaptive e-learning material can help teachers to deal with the heterogeneous inflow of students by offering the subject matter in a personalized manner [18]. For example, adaptive e-learning material provides tailored feedback on specific mistakes that students make. The feedback points out the mistake and guides the student to the relevant information, preferably in associated (online) documentation, in order to find the correct answer. The system can also adapt the amount of practice that students receive, so that those with little prior knowledge of a subject will practice more than students who have more prior knowledge. The opportunity to provide personalized education makes adaptive e-learning material a promising tool to educate heterogeneous student groups in biotechnology programmes. An adaptive e-learning system was developed as a result of the joint degree programme that Wageningen University set up with China Agricultural University within the framework of the FBT programme. The system lets students do exercises to practice applying the theory. The system adapts to an individual student by taking into account the pace at which he or she wants to go through the exercises, and by recording the number of incorrect answers the student gives in a certain category. The more incorrect answers a student gives, the more exercises he or she does. An extensive description of this system – called Proteus – is presented in Chapter 3.

1.5 Aim and research questions

The aim of this study was to evaluate the use of adaptive e-learning material in biotechnology education by students from different backgrounds. The research was both practically oriented as it aimed to support biotechnology staff who wish to use adaptive e-learning material in their classes and intended to contribute to recently reported science education research needs. These needs concern research into how individual differences in problem-solving strategies and styles, students' goals and motivational orientations, and students' meta-cognitive skills contribute to differences in studying in web-based learning environments [19]. The research reports in this thesis therefore targeted different audiences.

The following issues were investigated in this study. We identified which adaptive features of the developed system are used by students. We then investigated the influence that student characteristics have on their learning paths and strategies when working with adaptive e-learning material. The aim was to support the assumption that the use of adaptive e-learning material is beneficial when students have different backgrounds. The following research questions were addressed in this thesis:

1. In what way does adaptive e-learning material created with Proteus provide personalized instruction and how do students use and appreciate these adaptive features?
2. How effective is the adaptive e-learning material created with Proteus in generating a basic knowledge level within a heterogeneous student group?
3. Which student characteristics influence their learning paths and strategies when using adaptive e-learning material created with Proteus?

1.6 Research overview

Before the start of this research project, two adaptive e-learning modules (on cell growth kinetics and on enzyme kinetics) were available. These modules were improved after each session based on the feedback from students and teachers. They also were adapted to enable the research as described in this thesis. One module (on PCR primer design) and an evaluation instrument were designed, developed and improved during the research project. The studies that are described in this thesis are therefore conducted with different adaptive e-learning modules and with varying degrees of completeness of the evaluation instrument. The studies were measured in real classroom situations and therefore contain data from varying student groups at different institutions with different teachers. Table 1 gives an overview of the conducted studies.

Table 1. Overview of the studies that were conducted

Chapter	4	6	7	8
Subject	PCR primer design	Cell growth kinetics	Enzyme Kinetics	PCR primer design
Design method	Taxonomy of Educational Objectives	Unknown	Unknown	Taxonomy of Educational Objectives
Evaluation Instrument	Pre/post-test Questionnaire Traces	End-of course exam Small questionnaire No traces	End-of-course exam Questionnaire Traces	Pre/post-test Questionnaire Traces
Institution & period	Universities in Latin America Nov 2009 & Wageningen University Jan 2010	Wageningen University 2003-2005	Wageningen University May 2010	Wageningen University May 2011

1.7 Outline of this thesis

The chapters in this thesis cover one or more of the central research questions. Some chapters have already been published separately, which results in some repetition of content. This section describes the role of each chapter in answering the research questions. An overview of the study is presented in Figure 2.

General introduction
Context & aim: Chapter 1
Theory: Chapter 2

Research question 1
In what way does adaptive e-learning material created with Proteus provide personalized instruction and how do students use and appreciate these adaptive features?
Material: Chapter 3
Method: Chapter 5
Results: Chapters 4, 6, 7 and 8

Research question 2
How effective is the adaptive e-learning material created with Proteus in generating a basic knowledge level within a heterogeneous student group?
Material: Chapter 3
Method: Chapter 5
Results: Chapters 4 and 6

Research question 3
Which student characteristics influence their learning paths and strategies when using adaptive e-learning material created with Proteus?
Material: Chapters 3 & 4
Method: Chapter 5
Results: Chapter 8

General discussion
Reflection: Chapter 9
Implications: Chapter 10

Figure 2. Overview of the chapters in this thesis

The thesis contains four parts. Part I consists of an introduction to the research project, a description of the context of the experiment and the research questions (this chapter), and the theoretical background (Chapter 2).

Part II describes the material that was investigated in the study. Chapter 3 discusses and illustrates the adaptive features that Proteus contains. Chapter 4 focuses on the development of adaptive e-learning material in an objective way, and presents data on the learning outcomes of students before and after they had worked with the adaptive e-learning material. These results answer Research questions 1 and 2.

An evaluation of the learning material is presented in Part III. Chapter 5 describes the instrument that has been developed to measure the variables that are needed to answer the central research questions. Chapter 6 presents a retrospective analysis of data that were collected with the Cell Growth Kinetics Tutor. Logged numbers of exercises that students needed to finish, responses to questionnaire items, and end-of-course exam scores were analysed. This provided results for Research questions 1 and 2. Chapter 7 reports on a prospective study of the ‘Enzyme kinetics’ adaptive e-learning module. The adaptive features of this module were investigated in a new context with the instrument described in Chapter 5. Chapter 7 elaborates on the findings from Chapter 6 to answer Research question 1. Chapter 8 covers the relation between student characteristics and their learning paths and strategies. Chapter 8 combines the adaptive e-learning module described in Chapter 4 and the instrument from Chapter 5 to answer Research questions 1 and 3.

Part IV presents a general discussion of and reflection on the study (Chapter 9). This chapter summarizes all the major results and conclusions regarding the three central research questions. In it, we discuss the practical aspects of applying adaptive e-learning material and the contribution to the educational research on the personalization of learning with the help of computers. The experiences with the adaptive e-learning system are summarized into lessons learned (Chapter 10). In it, we give some suggestions for continued research on our findings based on the experiences we gained during the research. We also describe some improvements that can be made to the adaptive e-learning system.

Chapter 2
Background[1]

Adaptive e-learning can be used to personalize instruction for students in a heterogeneous group. Adaptive e-learning material is created with software systems that allow for personalized presentation of content. This chapter discusses the different terms that are used in literature to describe these systems. Proteus, the system that is investigated in this thesis establishes adaptation by providing tailored feedback, varying the amount of training and allowing for self-regulated learning (SRL) by students. In addition, this chapter therefore elaborates on theory of SRL and on feedback.

2.1 Adaptive e-learning

E-learning is defined by Shute and Towle [20] as 'learning that takes place in front of a computer that is connected to the Internet' (p.106). Adaptive e-learning is generally perceived from the instruction point of view and comprises computer-based learning systems that can interact with a student to provide the most appropriate instruction. Thus, it is not students' learning that adapts, but the instruction provided by the system. Adaptive e-learning is currently applied to improve the instruction given to heterogeneous student groups [21, 22].

Adaptive e-learning material has been investigated by multiple disciplines, including educational psychology and computer science, and each discipline uses its own terminology to label similar concepts. Adaptive e-learning systems consist of multiple components that together enable instruction that is tailored to the needs of the individual students. The names of the components, according to the terms used in educational psychology (with those from computer science given between brackets), are: the content model (domain model), the learner model (student or user model), the instructional model (interface model) and the adaptive engine [18, 20].

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1 Based on: J.R. van Seters, M.A. Ossevoort, J. Tramper & M.J. Goedhart (2011) The influence of student characteristics on the use of adaptive e-learning material. Computers & Education. http://dx.doi.org/10.1016/j.compedu.2011.11.002

The *content model* contains the concepts that a student should master. In educational research, the concepts are usually described as learning objectives, which combine the concepts with the actions that students should be capable of doing, such as remember, apply, understand, etc.

The *learner model* contains information about the individual student, such as preferences for textual or visual information, demographic data such as gender or age, and information about the knowledge of a specific topic. The information in the learner model can be obtained before commencement of the learning activity and does not change during the interaction with the system (static), or it can be updated during the interaction (dynamic) [23].

The *instruction model* monitors the learner model in relation to the content model in order to ascertain the student's mastery of concepts. As such, the instruction model determines how close a student is to the target competence level after carrying out a learning activity.

The *adaptive engine* is an algorithm that integrates information from the preceding models in order to select appropriate learning content to present to the student.

2.2 Self-regulated learning

Being able to regulate one's own learning is viewed by educational psychologists and policy makers as the key to successful learning at school and beyond. SRL refers to learning situations in which students set their own learning objectives. Students plan, conduct, regulate and evaluate the learning process individually to achieve their objectives. Monitoring and evaluating the learning progress are essential for successful SRL [19]. To allow students to reflect on their own learning, they should have control over their learning process. A way to provide self-control is by offering choices [24, 25].

A well-known driving force for SRL is intrinsic motivation. Students who are eager to study a subject and appreciate the learning environment engage more in self-regulated learning. In addition, the familiarity that students already have with the subject and the learning environment influences their use of self-regulated learning [26]. Other factors that influence self-regulated learning are, for instance, demographic characteristics such as gender or culture. Women are reported to score higher than men on help-seeking strategies, utility value and performance anxiety [27]. Cultural differences have also been reported to influence self-regulated learning [28]. In this study, Chinese students are less likely self-regulate their learning than Dutch students, since the former adopt a reproduction-directed learning style.

In a recent article, Winne [29] points out the problem of measuring SRL. Commonly used methods are inventories and think-aloud protocols, but these methods have some disadvantages. Inventories gather data after an intervention, relying on the memory of students. Think-aloud protocols alter the learning environment and natural behavior of the student. Computer-based learning environments (CBLEs) offer an alternative way to measure SRL by logging the student-interactions with the system, resulting in reliable data for educational research [29]. These 'traces' are gathered during interventions, on the fly and do not intervene with a student's natural behavior.

2.3 Feedback

Good feedback might strengthen the students' capacity to self-regulate their own performance [30] and is therefore an important aspect to take into account when investigating SRL. Feedback is defined as any message that is generated in response to a student's action [31]. Feedback usually indicates the student's performance in comparison with the expected one [32]. By doing so, feedback helps students to identify errors and become aware of misconceptions. Feedback also provides clues about the best approaches to correcting errors [31].

Feedback is most effective when it is tailored to individual students and helps them to proceed [33]. Many types and classifications of feedback have been reported, as has the effectiveness of each type. Feedback can be about the task (FT), the processing of the task (FP), self-regulation (FR) or the self as a person (FS). FT is the most common and is often called corrective feedback or knowledge of results. FT tells a student whether the answer he or she provided is correct or incorrect, such as: 'Your answer is correct, but you have to include more arguments to support your conclusion'. FP is more specific to the learning steps that are needed to perform tasks, such as: 'The order of the calculation steps you made was correct.' FR concerns the feedback students create for themselves. Self-regulation feedback is initiated by the student rather than by the teacher and can prompt the student to look for more information on a certain topic, without specific directions.

FS typically expresses positive evaluations, such as 'Well done' or 'Great effort', although it can be negative. It usually contains little task-related information and is rarely converted into more engagement, commitment to the learning goals, enhanced self-efficacy or understanding of the task [1]. Feedback on the processing of the task (FP) has been applied to intelligent e-learning by Narciss and colleagues [19], which they call informative tutoring feedback. Informative tutoring feedback provides strategically useful information that guides the student step by step towards successful task completion, thereby assisting multiple solution attempts. Informative tutoring feedback delivers instructions to solve the task successfully, by guiding and tutoring the learning process, rather than offering the correct solution [34]. Furthermore, students have to act in order to receive these instructions: they have to work on a task and, if they make a mistake, receive the informative feedback [19].

Computer-based feedback can be used to support teachers by taking over the labour-intensive task of providing explanations to common mistakes [35]. The biggest advantage of using computers is their ability to repeatedly provide immediate feedback on individual responses [31]. Computer-based feedback can be provided as local or global feedback. Local feedback is a specific response to student activities and is aimed at correcting errors and guiding students in solving the problem. Global feedback provides coaching for several aspects of the entire learning process [36]. Web-based feedback can provide tailored instructions by varying its content according to the individual characteristics and performance of the student, independent of the local computer that is used [35]. This type of feedback is called adaptive feedback and is often included in adaptive e-learning or intelligent tutoring systems.

Many best practices for the design of effective feedback have been reported in the literature. According to Kulhavy and Stock [37], effective feedback provides the student with two types of information: verification and elaboration. Verification is the simple judgement of whether an answer is correct or incorrect, while elaboration is the informational component that provides relevant cues to guide the student towards a correct answer [31]. Good practices regarding feedback in general are also well described by Hattie and Timperley [1]. These researchers report that feedback is most effective when it addresses faulty interpretations, not a total lack of understanding; provides cues or reinforcement to students; is in the form of video-, audio- or computer-assisted instructional feedback; and/or relates to goals. Feedback is more effective when it provides information about correct rather than incorrect responses. It is also effective when it consists of information about progress and/or about how to proceed. Good practices regarding computer-based feedback describe that response-specific feedback enhances student achievement more than other, general forms of feedback [31]. The types of feedback that are most effective depend on the level of the task. Delayed and knowledge-of-correct-response feedback may be more beneficial for lower-level learning, and answer-until-correct feedback may be more effective for higher-level learning [38].

Practices that should be avoided are also described in the literature. Feedback should not take too much time or provide too much irrelevant information [29]. FT about the task should not be mixed with FS, since the mix is reported to be less effective than FT on its own [1]. In addition, it is useless to present feedback to students who have no initial domain knowledge or completely lack the skills that are to be learned. In these situations, instruction is more useful than feedback. Feedback can only build on something; it is of little use when there is no initial learning or surface information (ibid.).

The adaptive e-learning system that was investigated in this research provides immediate feedback on both correct and incorrect answers. The feedback consists of general hints and specific feedback. General hints are presented upon the submission of any incorrect answer. This type of feedback incorporates aspects from feedback about self-regulation (FR). It for instance suggests to look for information, but does not provide detailed instruction about where to find this information. In addition, general hints can provide global feedback such as information about notation if the answer. Specific feedback directs students to specific information sources in case they have no knowledge to build on yet. As mentioned, instruction is more useful than feedback if the student's prior knowledge is too limited. The specific feedback helps the student to identify and understand the specific error that was made and guides him or her towards the correct answer. The feedback that is provided by Proteus is adaptive. The content of the feedback varies according to the individual performance of students. This performance consists of the type of mistake that was made, but also to the number of incorrect answers a student has already submitted. After many tries, more extensive feedback is given to help the student as is the case with informative feedback as described above.

Part II Description

This part describes the adaptive e-learning system and material that have been developed in this research project to answer the research questions formulated in Chapter 1. The system to create the adaptive e-learning material is described in Chapter 3. Some extensions and improvements to an older version of the system that were implemented during this study are described. Chapter 4 describes the design and development of new adaptive e-learning material about PCR primer design that was created to answer research question 3.

Chapter 3
The adaptive e-learning system

3.1 Introduction[2]

Adaptive e-learning material is widely used to offer personalized instruction [39]. Systems that provide adaptive e-learning are characterized based on *what*, *where*, *why* and *how* the systems can adapt [40]. Proteus adapts the amount of training and the content of feedback that students receive (the *what*) [22]. The adaptation of the amount of training and the feedback takes place during students' interaction with the e-learning system (the *where*). The amount of training is adapted to fulfil the needs of students who have little prior knowledge, but without imposing too much repetition on students who have more prior knowledge. The content of the feedback is adapted to target specific mistakes that students make (the *why*). The system varies the number of exercises according to the answers that the students submit to exercises related to the same learning objective. In addition, to establish the second mode of personalization (the *how*), the system lets students choose the next exercise according to three levels of complexity.

An overview of the flow of actions in Proteus is presented in Figure 3 on the next page in order to show how a student interacts with this adaptive e-learning material. The student starts by choosing a step size (small, medium or big). The system then selects an exercise with this step size and the student submits an answer. If the answer is correct, the maximum number of credit points previously assigned to the exercise is added to the learner model. If the answer is incorrect, the system presents feedback and hints. The student tries again until he or she gives the right answer. The number of credit points added to or subtracted from the learner model depends on the number of tries he or she needs.

[2] Based on: J.R. van Seters, J. Wellink, J. Tramper, M.J. Goedhart, & M.A. Ossevoort (2011). A Web-Based Adaptive Tutor to Teach PCR Primer Design. Biochemistry and Molecular Biology Education. http://dx.doi.org/10.1002/bmb20563

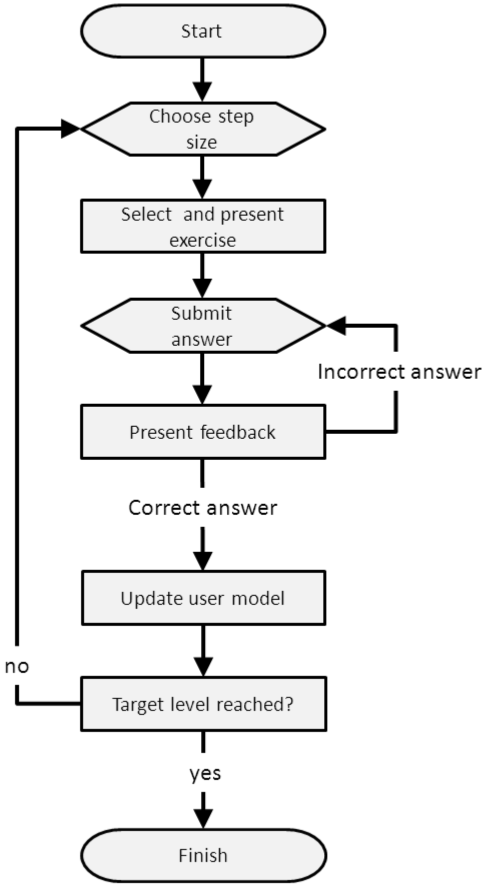


Figure 3. The flow model of Proteus. The actions that students execute are indicated with hexagons and the actions of the system with rectangles.

Thus, three parameters contribute to the adaptive features of the system. Two are system-driven: (1) the number of exercises that have to be done, which is determined by the distribution of credit points after incorrect answers and the selection of the next exercise, and (2) the presentation of feedback and hints. The other is student-driven, namely the choice of step size for the next exercise. The system thus offers a mixed form of regulation, in that students and teachers (in this case, the adaptive system) share the regulatory functions [41]. The use of these three parameters makes the system adaptive and allows for differentiated learning paths.

3.2 Content development

Adaptive e-learning material created with Proteus is built around a set of coherent learning goals selected by the developer. The developer is usually a lecturer who wants to integrate the material into a course, but can also be another expert in the field. Students can achieve the learning goals by doing exercises. The number of tries that students need to do the exercises correctly determines the speed with which they achieve the learning goals. The minimum number of exercises that students have to do to achieve the learning goals is set by the developer. This is done by assigning credit points to the exercises and setting a required threshold value of credit points that students have to obtain in order to achieve the learning goal. All students start at level zero for all learning goals, and finish by ending with the required threshold values. The paths students follow to achieve these threshold values vary between students, which makes the material adaptive.

3.2.1 Exercises development

The system can contain different types of exercises, namely option, check, value, drag & drop, hotspot, fill blanks, and select & order. Figures 4a-g on the next pages provide examples of the exercises types.

The option exercise is a multiple choice question (Figure 4a). Only one of the answers is correct and students can choose only one answer option. It is easy to assign scores for this type of exercise, since only one answer is correct. The chance of guessing the correct answer increases when the number of answer options is small, so we use a minimum of four answer options.

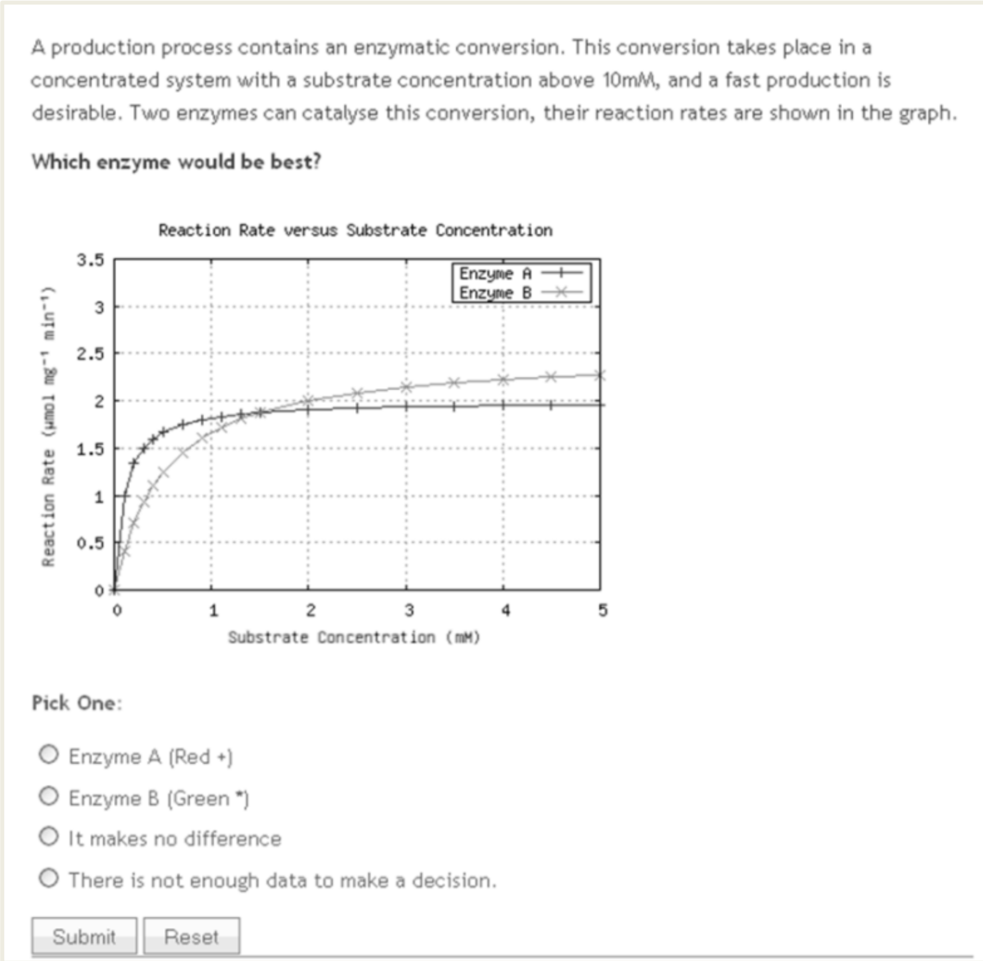
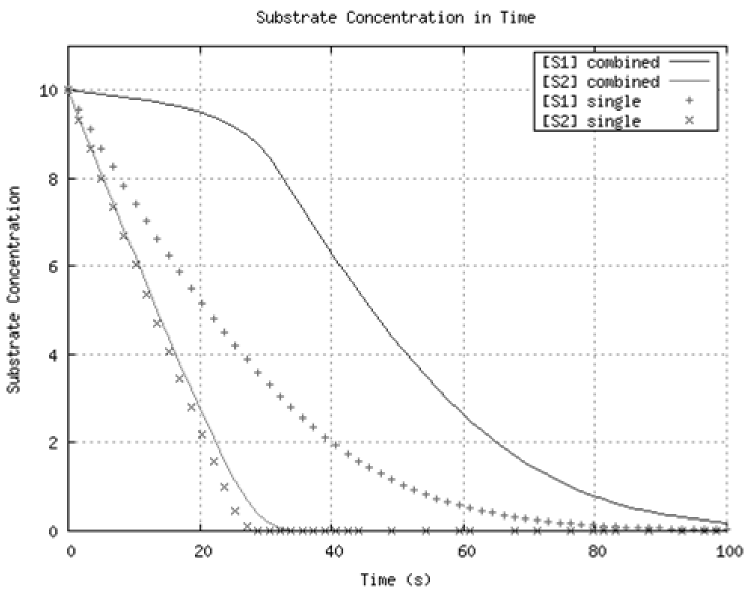


Figure 4a. Example of an option exercise

A check exercise is a multiple option question with one or more correct answer options (Figure 4b). As many answer combinations are possible, the chance of guessing the correct answer is small. Feedback can be given to individual answer options or to a combination of selected options, see also Figure 8 on page 47.

Shown are the concentrations of two substrates in three test-tubes, converted by one enzyme. One tube contained both substrates (solid lines), one tube contained only substrate 1 (blue +) and one tube contained only substrate 2 (purple x). All tubes contained the same amount of enzyme.



Which statements are true?

Pick any number:

- ☐ The enzyme has the highest affinity for substrate 1.
- ☐ The enzyme has the highest affinity for substrate 2.
- ☐ During the experiment the enzyme substrate complex is broken down and its activity stops.
- ☐ Substrate 1 is a competitive inhibitor for the conversion of substrate 2.
- ☐ Substrate 2 is a competitive inhibitor for the conversion of substrate 1.

Submit Reset

Figure 4b. Example of a check exercise

The answer to a value exercise is a number (Figure 4c). This type of exercise is mainly used for numerical problems. Because it is an open question, the chance of guessing the correct answer is small. The feedback can be designed for specific ranges of answer values.

Given a dataset in which the reaction rate is determined at various concentrations of a competitive inhibitor and a constant concentration of substrate. Given are the reaction rate and the amount of inhibition.

[I] (mM)	**v** (mmol mg^{-1} min^{-1})	**Inh** (mmol mg^{-1} min^{-1})
0	66.7	0.0
1	62.5	4.2
2	58.8	7.8
4	52.6	14.0
6	47.6	19.0
8	43.5	23.2
10	40.0	26.7
15	33.3	33.3
20	28.6	38.1
25	25.0	41.7
30	22.2	44.4
40	18.2	48.5
50	15.4	51.3
100	8.7	58.0
200	4.7	62.0

What is the rate at infinite inhibitor concentration?

mmol mg^{-1} min^{-1}

Submit Reset

Figure 4c. Example of a value exercise

A drag & drop exercise presents a picture that has blank spaces (Figure 4d). At the bottom right of a picture there are a couple of words or images (draggables), which have to be placed in the correct blank spaces (hotspots). The draggables can be moved and placed anywhere in the picture. The chance of guessing the correct answer depends on the number of draggables and hotspots. Feedback can be provided on specific draggable–hotspot matches or on a combination of these.

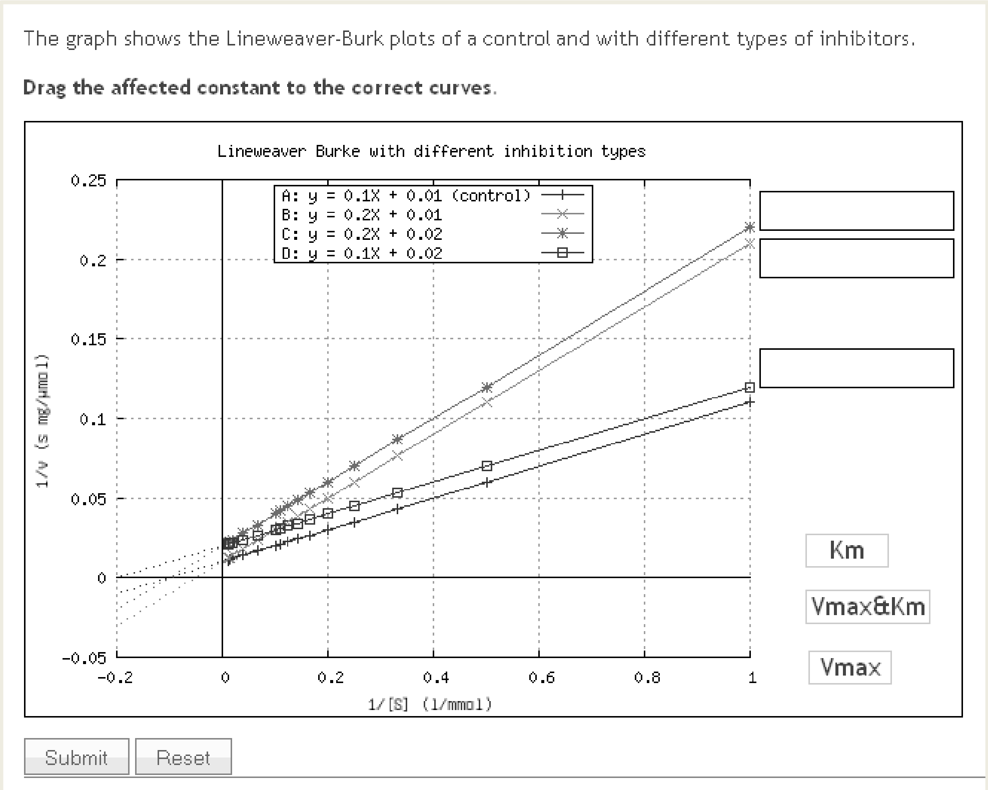


Figure 4d. Example of a drag & drop exercise

In a hotspot exercise, a picture is displayed (Figure 4e) and the student is asked to point out a specific object in the picture. The answer is submitted by clicking on the picture. Feedback can be given on specific locations.

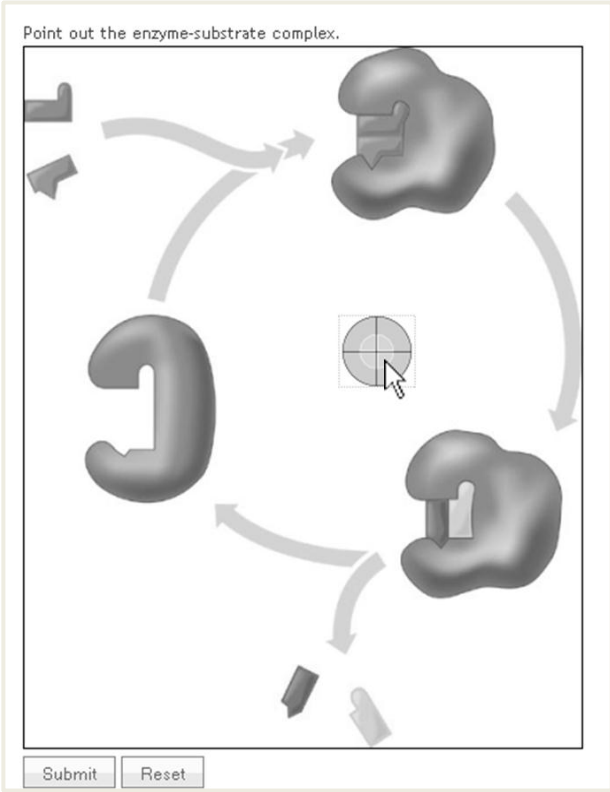


Figure 4e. Example of a hotspot exercise

The fill blanks question type contains text that provides a lot of information (Figure 4f). Blanks are inserted in certain places. Here, the student has to choose from a drop-down menu the correct word to insert. The same word options can be selected multiple times, resulting in a high number of possible answers and thus a small chance of guessing.

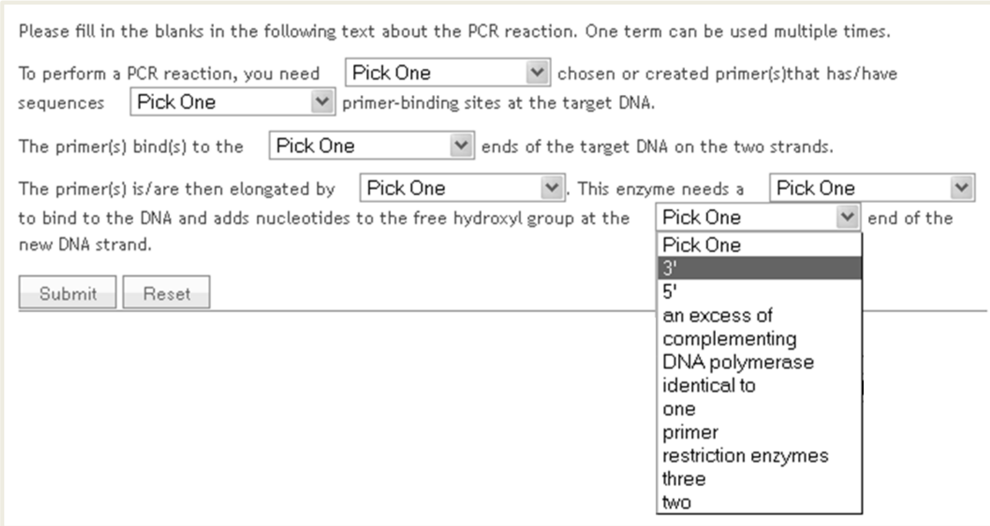


Figure 4f. Example of a fill blanks exercise

In select & order exercises, students select answer options from a list (Figure 4g). They also have to put the selected answer options in the correct order. This exercise is very useful in that it allows students to design an experiment by selecting the right steps to take, establishing the correct order in which to take them and dividing the steps over time.

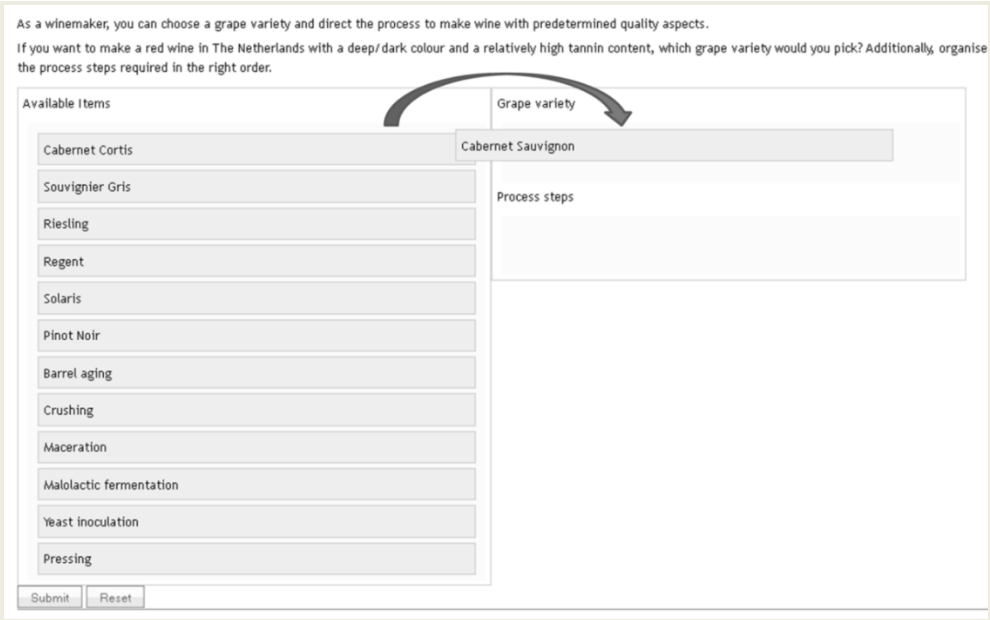


Figure 4g. Example of a select & order exercise

Students tend to adopt 'trial-and-error' behavior when using e-learning material [19]. We try to prevent students from guessing answers by, for instance, having multiple answer exercises (check) rather than multiple choice (option) exercises. In addition, students have to do more exercises if they give many incorrect answers. This feature has two advantages: it gives students who have not mastered the content a lot of practice and it prevents them from guessing.

3.2.2 Exercise calibration

The amount of credit points that is assigned to an exercise consist of start and end levels. The end level corresponds to the maximum progress towards the learning goal that students can achieve by doing the exercise correctly in one try. The start level is the minimum level that a student should already have reached in order to start an exercise. The start levels of exercises thus create a hierarchy in the order in which students can do the exercises (the system will only present exercises with a start level that the student has already reached). One exercise can have start and end levels for more than one learning objective. It is important to assign correct start- and end-levels to exercises, since these parameters determine which exercise students receive after selecting a steps size. Exercises are coupled to step sizes by their end levels, the difference between start- and end level is not taken into account. The relation between step sizes and exercise start and end levels is illustrated in Figure 5 on the next page. The calibration of exercises is usually done by assigning credit points to one or more learning objectives, and these learning objectives cover different topics. An adaptive e-learning module is then created by selecting the appropriate learning objectives. The associated exercises are then part of the module. It is thus possible to create multiple modules with the same set of exercises by selecting different learning objectives. This makes Proteus a very dynamic system.

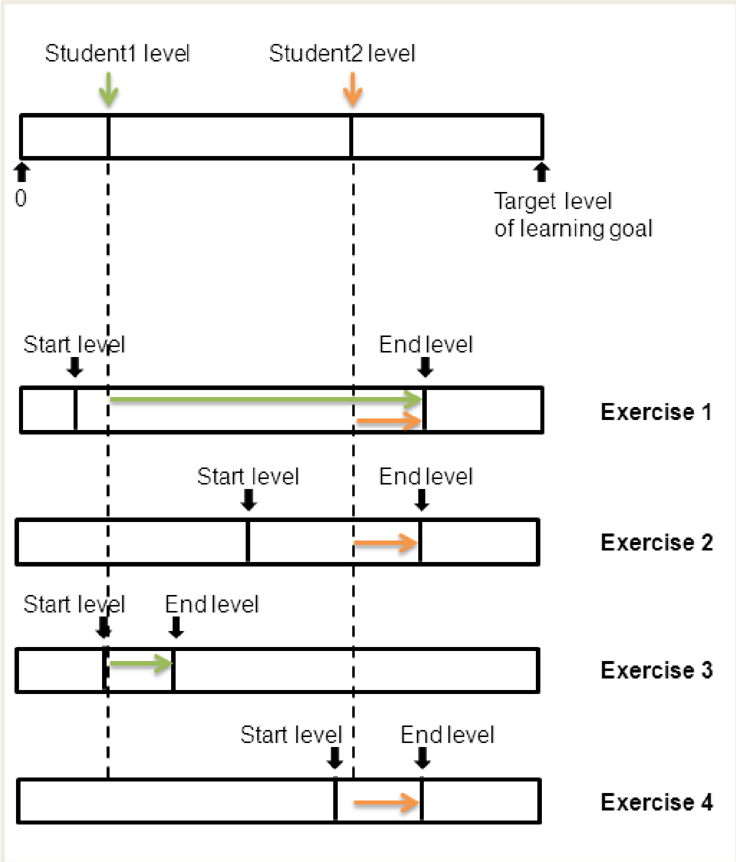


Figure 5. The relation between step size and the difference in begin- and and-level of the exercises is shown. Student1 will receive exercise 1 when selecting a big step and exercise 3 when selecting a small step. Student 2 can receive exercises 1, 2 and 4 when selecting a small step.

3.2.3 Online documentation

The adaptive e-learning material created with Proteus also contains online documentation along with the learning goals and the associated exercises. The documentation may contain texts, images, movies or presentation slides [42]. The documentation makes use of the possibilities that computer-based materials offer, by providing extra information on demand (e.g. the units and dimensions that are presented when students click on an equation; see Figure 6) and helping the student to navigate through the material by providing hyperlinks that connect sections on related topics.

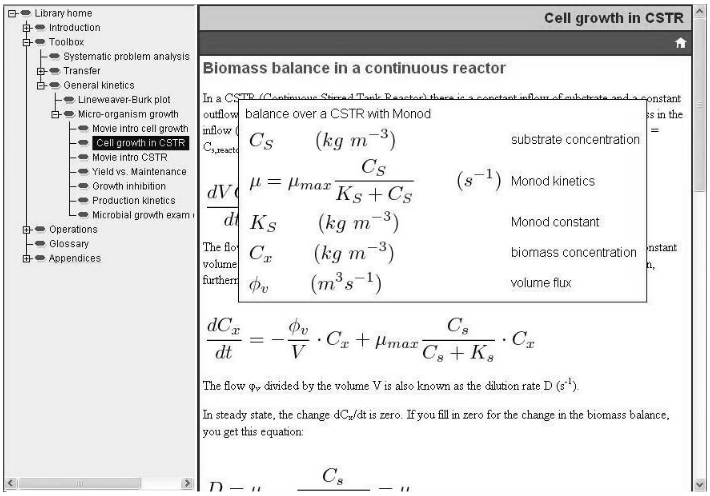


Figure 6. A typical feature of the online documentation of the Cell Growth Kinetics Tutor is shown. The pop-up appears when the mouse is rolled over the equation and provides extra information on the units and dimensions used in the equation [4].

3.3 Adaptivity

As stated, Proteus adapts to the student in three ways. The first way is student-driven, namely the choice of step size for the next exercise. The other two ways are system-driven, namely (1) varying the amount of training and (2) the presentation of tailored feedback and hints.

3.3.1 Student-driven adaptivity

The regulatory function driven by the students is the pace at which they will go through the material, as they select a step size before doing an exercise. The step size they select relates to the progress they can make towards the target level. Much possible progress relates to a big step and little possible progress relates to a small step. Before each exercise, students can adapt the step size, thus allowing them to reflect on their learning. This way of stimulating self-reflection is as example of an embedded direct intervention [19].

Students who have little knowledge and skill can take big steps to go through the material, but they will not necessarily finish faster. The system remembers the number of incorrect answers that were given and forces a student to do exercises until he or she can answer them correctly in the first (or second) time. This property of the system forces students to reflect. If they give many incorrect answers, it is better to take smaller steps or to study theory from the (online) documentation before submitting an answer.

The ability to choose a step size is reported to motivate students when they are using the learning material [43]. The ability to choose a step size is mainly connected to students' feelings of confidence and satisfaction, which is beneficial for their learning [44]. If students are insecure about their skills, they can choose to take small steps. On the other hand, if students choose small steps and thereby frequently submit correct answers, this adds to their feeling of satisfaction.

The possibility for students to choose different step sizes has another advantage: motivating students and allowing them to control their own learning stimulates self-regulated learning (SRL) [24], which occurs when students reflect upon their learning (a process called metacognition) and are conscious of their learning progress. As SRL strategies are reported to yield success in learning [41], the use of SRL should be stimulated.

3.3.2 System-driven adaptivity: varying the amount of training

The system selects appropriate exercises with regard to the current knowledge level of a student (the learner model), as described by Van der Linden and Glas [45]. To select appropriate exercises, the system compares the learner model to the content model, finds a training gap between these models and selects exercises that will fill this gap. The engine uses two input parameters to select an exercise to present to the student. These parameters are the training gap and the step size that the student chose. The system selects exercises after the step size selection by students in two steps:

1. All exercises that are appropriate considering the current learner model are selected. These exercises have a start level lower than or equal to the student level and an end level higher than the student level.
2. The system selects an exercise equal to the step size selected by the student.

The learner model is updated after each exercise for the involved learning goal(s). More tries result in a smaller change in the student level. The algorithm the system uses to calculate the new learner model follows three rules (Figure 7):

1. If the difference between the student level and the end level of the exercise is small, the student cannot win or lose many points. Thus, if two students

need the same number of tries to do an exercise, but student 2 has a higher student level than student 1, student 2 will obtain fewer points than student 1.

2. Giving a correct answer in one try is awarded. Students are stimulated to give correct answers in one try. This is to prevent students from guessing at first and then use the feedback to find the correct answer when they could also have found the answer without help. This is reflected in the scoring system.
3. The calculated gain is relative, so if learning objectives within the material differ a lot in their target levels, the gain also varies.

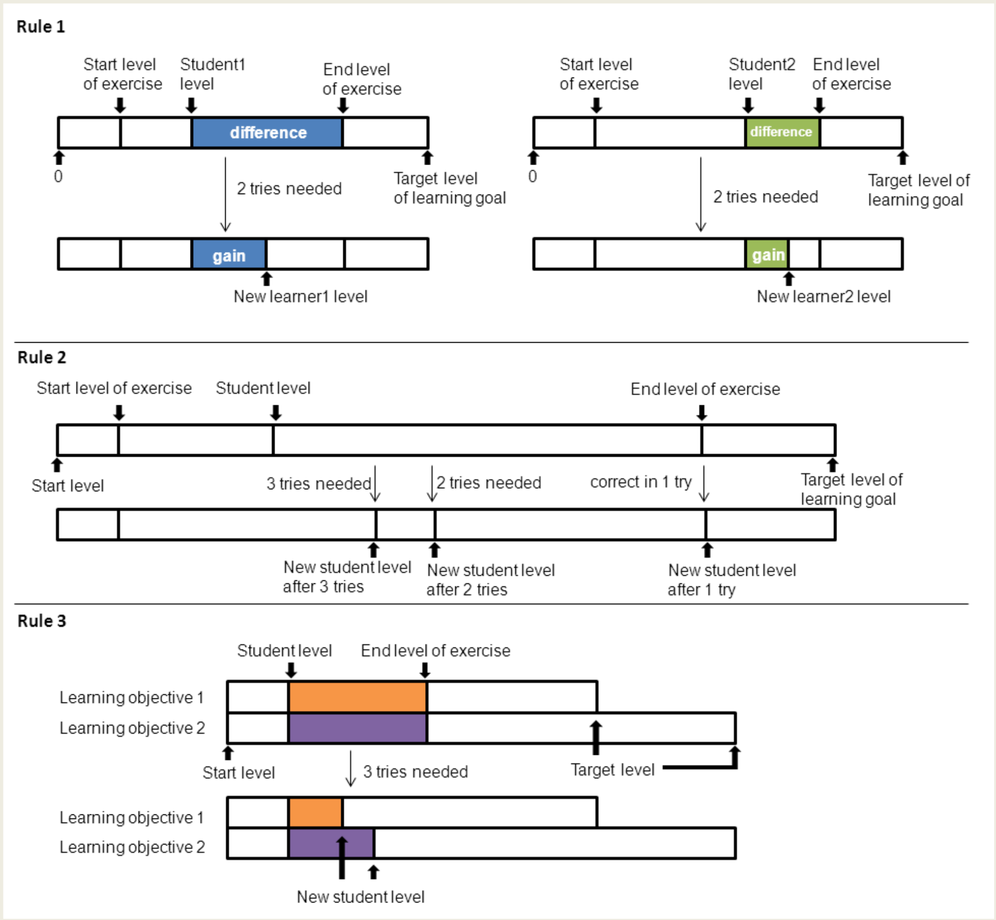


Figure 7. Three rules followed by the algorithm that Proteus uses to update the learner model

Because students receive fewer points when they need more tries to complete an exercise, the number of exercises that students need to do to finish the module varies. This feature contributes to personalized instruction. Students who have the required knowledge and skills are assumed to do exercises correctly in one go. If they choose the big step option, they will not need many exercises to complete the material. Students who do not have the required knowledge and skills need more tries and do more exercises. Every student will therefore receive the training required to achieve the learning goals, but needless repetition is avoided.

3.3.3 System-driven adaptivity: tailored feedback and hints

The system provides tailored feedback to students, which is reported to have a positive influence on their learning [46]. An example exercise with feedback is presented in Figure 8. This exercise is a multiple answer (check) exercise about PCR primer design. The feedback that is presented follows a simple path. If an answer is incorrect, two types of feedback are presented (Figure 8a). The first type is a general hint, the content of which depends on the number of tries the student has made. A hint directs the student to general information about the subject, or provides the correct answer after many tries to prevent the student from becoming stuck. Common mistakes in entering answers (such as using commas instead of points for decimals) are pointed out in general hints. In the example, the general hint provides the student with information about the number of options that should be selected. The second type provides information about a specific incorrect (combination of) answer option(s). This specific feedback points out the mistake that was made and directs students to relevant information sources (see the link to 'library' in Figure 8a). If an answer is correct, the feedback to a correct answer is presented and the possibly present previous feedback on incorrect answers is no longer shown (Figure 8b). The student receives information about why the answer is correct and sometimes also hyperlinks to documentation about the specific subject. Students read the explanations and then proceed with the next exercise. The location of the feedback text depends on the type of feedback and the type of exercise. In multiple option exercises the specific feedback is presented directly after the incorrect answer option, so students know to which answer the feedback refers. The general hints and feedback on correct answers are always located at the bottom of the exercise page (Figure 8).

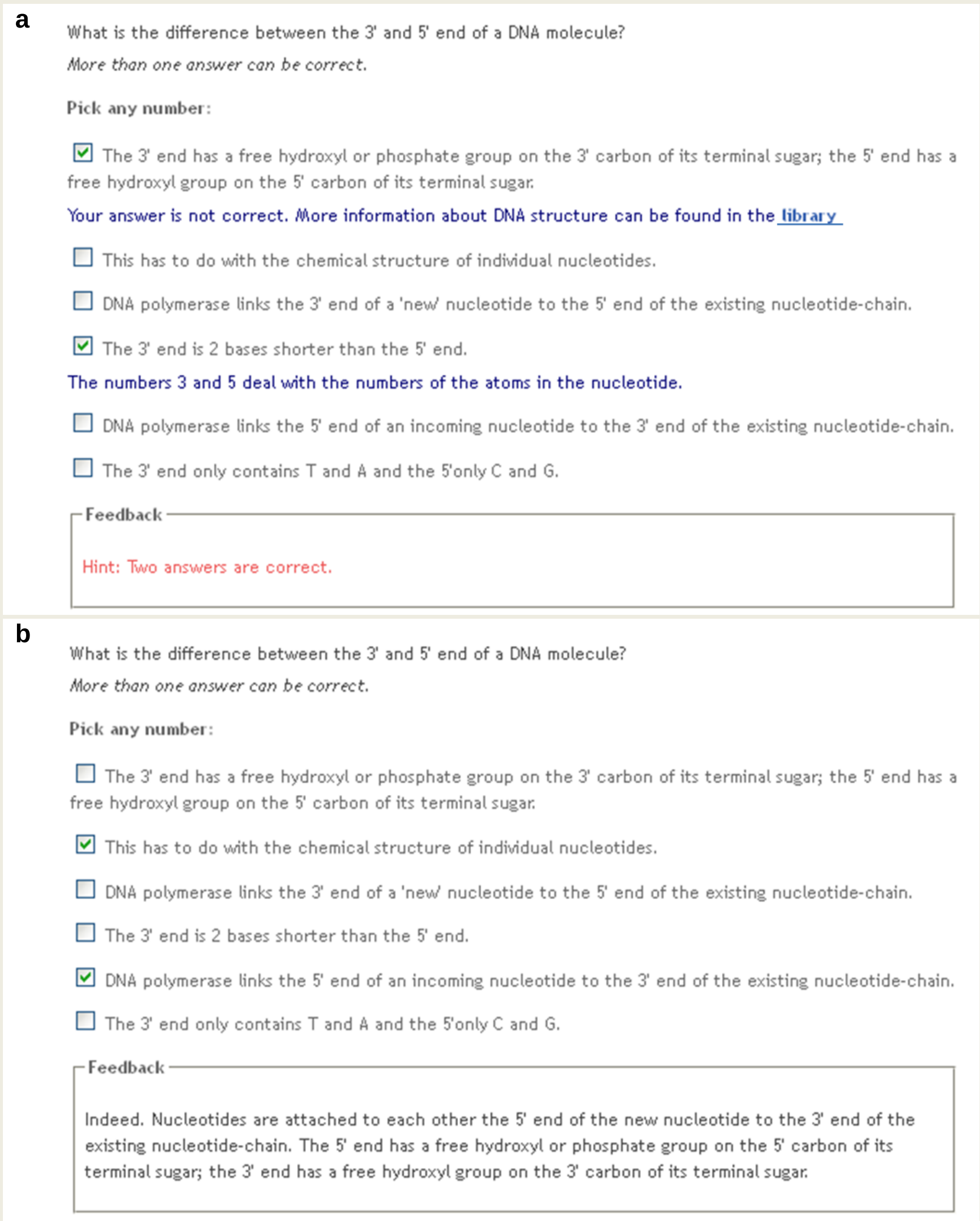


Figure 8. An example exercise with (a) specific feedback (in blue) and a general hint (in red) and (b) the feedback to the correct answer, shown at the bottom of the exercise

3.4 Authoring tools

Proteus is designed to be a teacher-friendly tool to create adaptive e-learning material [47]. A developer has to assign only a small amount of information (metadata) to an individual exercise, and a teacher only has to link an exercise to one or more defined learning objectives and add the start and end levels of the exercise for the learning objectives. The use of the authoring tools is described in a manual, which is available at: http://wmmrc.nl/drupal-modules/manual.

3.5 Availability and access

We designed the system using open-source software packages. These packages are available for download at http://wmmrc.nl/drupal-modules/download. The packages can be implemented in Drupal, which is a widely used open-source content management system. To reduce the number of login accounts that students need, additional software packages have been developed to enable access via Blackboard or Moodle.

Chapter 4
An alternative design method[3]

4.1 Introduction

In recent years, student mobility has increased due to the Bachelor-Master system in higher education in the EU. This increased mobility has resulted in greater diversity in the background and prior experience of students who enter molecular biology courses. The difference in prior education means that not all students have the knowledge needed for the Master's course in which they wish to enroll. Compared to the former situation where student populations entering higher education were similarly prepared, this increased heterogeneity requires a more personalized approach to instruction.

Personalized instruction should be adapted to the individual student's characteristics. It also facilitates learning that is independent of time and location [48]. In line with the theory of constructivism [49], students start their learning process at the edge of their prior knowledge, moving towards a level that is needed to enroll in and successfully complete a course. Personalized instruction is expected to offer extra instruction to students who have relatively little prior knowledge.

One way to accomplish personalized instruction is by using adaptive e-learning material [12] to present exercises of different levels [22]. The complexity level of these exercises was previously calibrated using the teacher's intuition and experience [5]. Although teachers may have a good sense of the difficulty perceived by students, this is a very subjective method and prone to mistakes. In addition, some teachers have difficulty designing and interpreting the calibration of exercises that is described in section 3.2.2. They want to assign complexity levels to exercise levels related to the step sizes that students select. In this chapter, we present an alternative way to design the adaptive e-learning material and to calibrate exercises. We do so by dividing the learning objectives into sub-learning

[3] Based on: J.R. van Seters, J. Wellink, J. Tramper, M.J. Goedhart & M.A. Ossevoort (2011). A Web-Based Adaptive Tutor to Teach PCR Primer Design. Biochemistry and Molecular Biology Education. http://dx.doi.org/10.1002/bmb20563

objectives. This way, it is possible to assign a complexity level to an exercise which is independent of the student level.

To study this, we developed a web-based adaptive tutor to teach PCR primer design (the PCR Tutor), where the complexity level of the exercises was calibrated using the Taxonomy of Educational Objectives described by Krathwohl [50]. In addition, we determined the learning outcomes of students and their perception of using the PCR Tutor.

4.2 Materials and methods

4.2.1 Calibrating complexity

The exercises that students are assigned are calibrated to achieve adaptive e-learning that offers training at three complexity levels. Systematic calibration of the complexity of these exercises is performed by using an educational taxonomy. To calibrate the exercises in our adaptive e-learning system, we chose the Taxonomy of Educational Objectives, which was initially described by Bloom [51] and revised by Krathwohl [50]. This taxonomy presents six categories of cognitive processes that a student needs in order to carry out given tasks. In order of increasing complexity, these six categories of cognitive processes are: remember, understand, apply, analyze, evaluate and create. The cognitive processes are supposed to be hierarchical, i.e. the processes have increasing complexity, and each category requires the achievement of the prior skill or ability before the next more complex process can be executed.

Because the adaptive e-learning system used in this study lets student choose between three levels of complexity, we focused on the three first levels from the taxonomy: remember (knowledge), understand (comprehension) and apply (application), see Table 2 on page 53. Remembering is defined by Krathwohl [50] as "retrieving relevant knowledge from long-term memory" (p. 215) and includes recognition and recall of information. Understanding concerns "determination of the meaning of instructional messages" (p. 215) and includes student activities such as interpreting, exemplifying, classifying, summarizing, inferring, comparing and explaining. Application refers to "carrying out or using a procedure in a given situation" (p. 215) and includes activities such as executing a task or implementing a plan. The three categories were used to design exercises at three complexity levels. Together, these exercises formed the adaptive e-learning module.

4.2.2 PCR primer design

Adaptive e-learning has been reported to be effective when students vary in their prior knowledge on a specific subject [22]. To carry out our research, we selected a topic that is part of higher education and for which students have varying background. We selected the topic of Polymerase Chain Reaction (PCR). This is an important technique in molecular biology research that is used amplify specific DNA sequences [52]. We expected that the topic of PCR would be familiar to some students and not to others, since some students would have had training in basic molecular biology techniques (e.g. students from undergraduate life science programs) while others would not have (e.g. student from undergraduate chemical engineering programs).

The technique of PCR requires students to design two primers that are specific for the DNA sequence of interest. Designing primers is an aspect that is often overlooked in experimental design [53] and students have difficulty with this task. Research on teaching the basic concepts of PCR has been reported before [54, 55]. Robertson et al. [55] reported that active practice with the design of primers on paper helped to improve students' understanding. We built on these findings by having students practice designing primers themselves. Philips et al. [54] identified the following misconceptions of students regarding the design of primers for PCR: both the forward and the reverse primers bind to the same strand of the given DNA sequence, the direction of DNA replication can be 3′–5′, PCR primers cut DNA and all DNA is amplified in a PCR reaction. The adaptive e-learning exercises that we developed provide feedback about common mistakes. We integrated the misconceptions identified by Philips et al. [54] in the available answer options of the exercises.

4.2.3 Research aim

The aim of this study was to develop exercises for a web-based adaptive tutor about PCR primer design (PCR Tutor) with calibrated levels of complexity. We measured the objectivity of this method by calibrating the exercises by two raters and calculating the inter-rater agreement. In addition, we measured the learning effect of the developed module with a pre- and post-test, and we measured the students' perception of using the module with a questionnaire. We formulated the following research questions:

1. Can we use the Taxonomy of Educational Objectives to calibrate exercises for an adaptive PCR Tutor in a systematic way?
2. What is the learning effect of the PCR Tutor?
3. What is students' perception of the PCR Tutor?

4.3 Design of the tutor

First, we formulated a total of nine learning goals covering the three basic categories of cognitive processes (remembering, understanding and applying) to provide a framework to design the exercises of the PCR Tutor (Table 2). The overall learning goal deals with the ability of students to design PCR primers with the correct directionality, and belongs to the third complexity level of the taxonomy (apply). The concepts that students need to understand to achieve this overall learning goal are formulated in three learning goals that belong to the second complexity level (understand). Students who master the overall learning goal of the third complexity level then have to master the learning goals from the second complexity level. Some terms are needed to understand the concepts of PCR primer design and remembering these terms is the focus of the five learning goals that are formulated for the first complexity level of the taxonomy (remember).

Table 2. The learning goals formulated for the PCR Tutor using the three basic cognitive process levels (from high to low) of complexity of the Taxonomy of Educational Objectives.

Cognitive process	Learning goal(s)
Apply	Students **design** PCR primers with the right directionality.
Understand	Students **understand** that the right directionality is needed to obtain the desired DNA fragment (and can **deduce** what will happen if the directionality is wrong). Students **understand** that the nature of DNA structure (binding in an anti-parallel complementary way) allows for the design of primers that amplify a specific part of the DNA. Students **understand** that two primers (forward and reverse) are needed to perform PCR.
Remember	Students **know** the terms 3’end and 5’end. Students **know** that DNA polymerase can only extend into one direction. Students **know** that DNA polymerase needs a primer. Students **know** that DNA consists of two nucleotide strands that bind to each other in an anti-parallel manner. Students **know** where the forward and reverse primers bind to the DNA.

After the nine learning goals were formulated, a maximum of three exercises with feedback were written for each learning goal. Multiple exercises per learning goal were needed because students had to complete additional exercises when they answered incorrectly. Three types of exercises were designed: multiple choice, multiple answer and select-and-order. The multiple choice and multiple answer exercises contained incorrect answer alternatives, and connected to common misconceptions that were identified in previous research [54]. In addition to these reported misconceptions we investigated additional pitfalls. To do this, five PhD students who did not work with PCR on a daily basis made the exercises in their open-ended form (i.e. without answer alternatives to choose from). Their answers were analyzed for common misconceptions or mistakes when completing the exercises. These misconceptions were included as realistic incorrect answers in the exercises. All exercises were entered in Proteus. Specific feedback on misconceptions was included for each exercise.

4.3.1 Implementation of the tutor

The PCR Tutor was tested during computer-sessions at several universities, and was improved afterwards. The tests were done with students whose prior knowledge on PCR varied. After the first experiment, improvements were made to the PCR Tutor. For example, students had difficulties with the feedback on multiple option questions. The feedback to these question types was then changed to make it clearer when one answer option was correct, but another correct answer option was still missing.

Students' learning was assessed in two rounds. In the first experiment, the PCR Tutor was given to 74 students at different universities in Latin America. For some students the PCR Tutor was part of their course, for others it was not. The students had a background in chemical engineering or biotechnology. The participants were both undergraduates and postgraduates, so we expected them to have different levels of prior knowledge. In the second experiment, the PCR Tutor was implemented at the beginning of a molecular biology course for first-year undergraduates at Wageningen University in the Netherlands. The 110 life science students in this experiment differed in their pre-university education, so we again expected them to have different levels of prior knowledge.

4.3.2 Evaluation of learning effect

Students' learning was assessed by testing their understanding before (pre-test) and after (post-test) the PCR Tutor. Both pre- and post-test consisted of the same type of assignment: the students were asked to design primers for a given DNA strand. The DNA sequence in the pre-test differed from that in the post-test. The formulation of this assignment was taken from the literature [55]. It was similar to the exercises that belonged to the highest level learning goal in the PCR Tutor, but it was phrased as an open-ended question (Figure 9).

The pre- and post-test results were analyzed using the scoring model shown in Table 4 on page 58. Students could obtain 1 to 6 points, with only integer values. The answers were also scored by a second rater. The scores given by the first and the second rater matched 100%, so the scoring model was very reliable.

Figure 9. The pre- and post-test that were developed for the adaptive e-learning module described in Chapter 4 (the PCR Tutor)

4.3.3 Students' perception

The perception of the students about the PCR Tutor was measured with a questionnaire. The questionnaire consisted of statements for which students could indicate their agreement on a 5-point Likert-scale, and one open question to ask about their opinion. The open ended question reads: 'Please write down frankly what you think about the PCR Tutor as extensively as you can: we would like to receive your personal opinion'. In the first experiment, the appreciation of the students was measured by averaging ten items from the questionnaire. In the second experiment, this measurement was condensed to six items to minimize the required effort from students. (Table 3 on the next page)

Table 3. Items from the questionnaire to which student could respond on a 5-point Likert-scale. (1=strongly disagree, 2=disagree somewhat, 3=neutral, 4=agree somewhat, 5=strongly agree)

Items in experiment 1	Items in Experiment 2
This module is boring.*	This module is boring.*
This module challenged me.	This module challenged me.
I liked working with this module.	I enjoyed this module.
This module motivates me to think about the theory.	This module motivated me to think about PCR Primer Design.
This module makes learning PCR more interesting.	This module made learning about PCR Primer Design more interesting.
This module is a nicer way to study the theory than making assignments on paper.	I preferred this module on PCR Primer Design to traditional learning material.
I prefer using this digital module to study PCR.	Item was removed.
It is nice to work with the digital module.	Item was removed.
This module is useful.	Item was removed.
This module is motivating.	Item was removed.

** This item was recoded (inverted) before averaging the item-responses.*

4.4 Results and discussion

4.4.1 Categorization of the exercises

The development of exercises by using categorized learning goals is supposed to be an adequate way to obtain exercises with different levels of complexity. To test the expert validity in categorizing the learning goals and assigning the exercises to the learning goals, both were presented to a researcher in biology education who acted as the second rater. The researcher was first asked to categorize the given nine learning goals according to the three levels and then to assign the exercises to these learning goals. The researcher's results were compared to the author's categorization using joint-probability of agreement. The categorization of the learning goals matched for 89%. The assignment of the exercises to the learning goals matched for 74%, which was considered sufficient. After the inter-rater agreement measurement, the developer and the researcher agreed upon the classification of all exercises and learning goals.

4.4.2 Outcome of learning effect

To measure the effectiveness of the PCR Tutor, we looked at the percentage of students that mastered the learning goal before and after using the PCR Tutor. Students mastered the learning goal if they scored 5 or 6 points on the test assignment (Table 4 on the next page). The results from the pre-test showed that the students in both experiments varied in the prior knowledge they had. Some of the students – 12.2% in the first experiment and 19.9% in the second experiment – already mastered the learning goal before using the PCR Tutor. The percentage of students that mastered the learning goal after finishing the PCR Tutor increased to 59.5% in the first experiment and 85.7% in the second experiment. Therefore, 47.3% of the students in the first experiment and 65.8% of the students in the second experiment achieved the learning goal by completing the exercises from the PCR Tutor. The second group achieved a larger learning effect than the first group. This increase was probably due to the improvements of the Tutor and the differences between the student populations. In the second experiment, 14.5% of the students still did not achieve the learning goal. Most of these students (8.2%) designed primers with the right DNA sequence, but with incorrect directionality or labeling.

Table 4. Scoring model and results of the test assignments with the percentages of students that earned each score

Score	Description	Experiment 1 (n=74)		Experiment 2 (n=110)	
		Pre	**Post**	**Pre**	**Post**
1	Student had no idea or gave no answer.	16.2%	1.4%	19.1%	2.7%
2	Student replicated the DNA (wrote down complete complement of the given DNA strand).	50.0%	20.3%	20.0%	2.7%
3	Student designed two primers, but they both bind to the same strand (the given strand).	20.3%	0%	29.1%	0.9%
4	Student designed two primers with the correct DNA sequence, but with the wrong directionality (3' and 5' switched) and/or the forward and reverse primers switched.	1.4%	18.9%	12.7%	8.2%
5	Student designed primers with the correct DNA sequence, the right directionality (assuming the general notation (5'→3') was used) and the correct forward and reverse primer (assuming the forward was given first and the reverse last). However, the student forgot to indicate the directionality and/or to label the forward and reverse primer.	8.1%	31.1%	15.5%	53.6%
6	Student designed two primers with the correct DNA sequence, labeled forward and reverse primer correctly and indicated the directionality correctly.	4.1%	28.4%	3.6%	31.8%

4.4.3 Students' perception

The students were moderately positive about the use of the PCR Tutor. The mean response to the appreciation items on a 1-5 Likert-scale was 3.9 (SD = 0.6) in the first experiment and 3.3 (SD = 0.7) in the second experiment. On the open question, students indicated they really liked the personal feedback that is part of the PCR Tutor, as can be judged from these quotes:

- *'My background about PCR technique is not so big. So, all small steps help to me to learn about the basic concepts of PCR. The figures, the questions and the directions are so clear and the feedback is a good tool.'*
- *'First of all I believe [it is] interesting to learn in a way totally different that I already had experienced in my whole academic life. ... For us (students of chemical*

engineering) [it] is pretty boring to understand this kind of subject like PCR, but now after this module, it was awesome to learn in this interactive way. Keep working!

- *'I think it is a good tool to learn the subject due to the feedback after giving the wrong answer.'*

4.5 Concluding remarks

This study shows that it is possible to calibrate exercise levels using the Taxonomy of Educational Objectives to develop an adaptive tutor. We developed a web-based adaptive tutor to teach PCR primer design: the PCR Tutor. The PCR Tutor was effective in teaching PCR primer design to students with varying levels of prior knowledge of PCR, and students appreciated this personalized instruction.

4.6 Suggestions for further research

The Taxonomy of Educational Objectives proved useful for designing adaptive e-learning. Further development of adaptive e-learning material on other subjects using this taxonomy is therefore recommended.

The adaptive tutor to teach PCR primer design proved to be effective. However, the PCR Tutor is limited. It covers only one of the issues encountered when designing PCR primers: the directionality of the primers. Therefore, we recommend that the Tutor is expanded with other exercises such as CG-content and the specificity of the primer for the target organisms.

This study was part of a research project that investigated the use of web-based adaptive tutors by students with different backgrounds. Continuing research in this project will focus on the differences in learning that students adopt related to their individual characteristics, such as prior knowledge, gender and cultural background.

Part III Evaluation

The study aims to evaluate adaptive e-learning material by observing student interactions with adaptive e-learning material and by measuring their perceptions of the material. An evaluation instrument was developed and tested for reliability and validity to measure the student interaction and perception. The evaluation instrument consists of a questionnaire, logged traces from student interactions with the adaptive e-learning material and test scores and is described in Chapter 5. The evaluation instrument is applied in different contexts to obtain data that will answer the three central research questions. Chapters 6 and 7 answer research questions 1 and 2 for the adaptive e-learning material on cell growth and enzyme kinetics, respectively. Chapter 8 gives the results to answer research question 3 using the evaluation instrument from Chapter 5 and the PCR Tutor from Chapter 4. The chapters were submitted for publication independently and some content is therefore repeated.

Chapter 5
The evaluation instrument

The research that is described in this thesis targets two audiences (see also section 1.5 on page 17). On one hand, the research aims to provide practical guidelines for teachers who wish to use adaptive e-learning material in their courses. Our aim is to guide teachers in the selection of appropriate learning activities that have been shown to be effective. On the other hand, the research aims to contribute to the field of educational research by providing insight in the way students self-regulate their learning. To reach these aims, we evaluate the adaptive function of e-learning material. To carry out this evaluation in a systematic way, we designed an evaluation instrument that yields data for both goals.

5.1 Purpose

The purpose of the evaluation instrument is to collect specific variables to answer the research questions formulated in Chapter 1. These variables are described below, grouped per research question. An overview of the variables is presented in Table 5 on page 65.

The first research question deals with the features of adaptive e-learning material and students' appreciation of these features. As stated in chapter 3, e-learning material created with Proteus has three different features that allow for adaptation to the student. The first feature is the ability for students to choose the pace to go through the material. The appreciation of the students for the ability to choose the step size is measured and this variable is called *appreciation of step size choice*. The second feature is the ability to provide tailored feedback to students. The use of the feedback is measured by the extent to which students read the feedback to correct and incorrect answers. These data are part of the variable *use of feedback*. The appreciation of the students for the feedback is also measured and this variable is called *appreciation of feedback*. The third feature comprises the variation of the number of exercises that students have to make, based on the number of incorrect answers they submitted. The variable that is measured is called the *number of exercises* and the appreciation of students for this adaptation is called *appreciation of number of exercises*.

The second research question concerns the effectiveness of adaptive e-learning material created with Proteus to obtain a basic knowledge level within a heterogeneous group of students. To answer this question, we need to assess student achievement. We will measure the variables *prior knowledge* and *learning outcome* to assess student achievement. In addition, we need to measure the degree to which the student population is heterogeneous with regards to specific aspects, such as prior knowledge, motivation and cultural background. For this purpose, we will measure *demographic data* of the students, namely gender, phase of education and nationality).

The third research question asks about the influence of individual student characteristics on their use of the adaptive e-learning material created with Proteus. To answer this question, we need information about student characteristics that are likely to have an influence on their learning paths and strategies. Student characteristics that are likely to have an influence include *demographic data* and *motivation*.

The learning paths that students follow is measured by the *number of incorrect answers* students gave, their *step size choices*, the *number of exercises* they needed and the *time* they *needed* to finish. The strategies students use when working with the adaptive e-learning material is characterized by the approach they use to make the exercises and the degree to which they self-regulate their learning. Information about the used approach to make the exercise, also called problem-solving method, is measured by the variable *approach to make exercises*. Self-regulation is measured by relating the *step size choices* to the *number of mistakes made*. In addition, the information sources that students use while making the exercises are measured to indicate self-regulated learning. The variables to measure the use of information sources are: *use of feedback* and *use of other information sources*.

Table 5. The variables that will be measured to answer the research questions and the associated instruments

What is measured:	Variables	Instrument:
	Independent:	
student characteristics	demographic data (gender, phase of education, nationality)	Questionnaire
	motivation	Questionnaire
	prior knowledge	Test
student achievement		
	Dependent:	
	learning outcome	Test
problem-solving strategies	the approach to make exercises	Questionnaire
learning path	time needed	Traces
self-regulation	step-size choice	Traces
	number of incorrect answers	Traces
adaptivity	number of exercises	Traces
	use of feedback	Questionnaire
use of information sources	use of other information sources	Questionnaire
	appreciation of step-size choice	Questionnaire
appreciation	appreciation of feedback	Questionnaire
	appreciation of number of exercises	Questionnaire

5.2 Instrument selection

Section 5.1 focussed on *which* variables are needed to answer the research questions of this thesis. This section will answer the question *how* these variables will be measured. The answer is also summarized in Table 5.

Of the set of variables that we want to measure in our study, two variables can be measured with student monitoring by assessments: *prior knowledge* and *learning outcome.* The prior knowledge of students can be measured by an assessment before the intervention. The learning outcome of students will be measured in two ways. The first approach is to take a test directly after the intervention. Another approach is to include one question about the subject of the adaptive e-learning material in the regular end-of-course exam to form a delayed test.

Demographic student data was collected by a questionnaire or be retrieved from the student administration department of the university. Both methods are used in this thesis. There are different views on where to place the items about demographic data in a questionnaire. The most common places are at the beginning or at the end of the questionnaire. An argument to place these items at the beginning of the questionnaire is that they are easy to answer and give the participant a relaxed start. An argument to ask about demographic data at the end of the questionnaire is that participants might feel they already invested in the questionnaire and are therefore more eager to give their personal data. We chose to place the items at the end of the questionnaire. The demographic data that we obtained are: gender, study level, nationality, prior education and age.

The used problem-solving strategies and the use of information sources can be measured in different ways. Our study aimed to investigate the use of the learning material in an authentic setting, so laboratory set-ups are not feasible. We also aimed to obtain information of complete classes, so we needed easy-to-process quantitative data to perform the analyses. We therefore chose for questionnaire items to collect data about the problem-solving strategies and information sources that students used.

Three variables concern the measurement of appreciation by the students and one their motivation. Since we want to perform quantitative data analyses, we chose to design a survey. We used scales that typically consist of multiple items to yield the highest <u>reliability</u> [56]. Reliability of attitude scales is measured by calculating correlation coefficients, such as Cronbach's alpha of the items. Measuring the <u>validity</u> of items is more difficult. We interviewed representative participants and discussed the content of the items with them.

The learning paths are assumed to vary between students. We gain insight in the learning paths by measuring the time needed to finish, the number of exercises students need to finish, the step size choice that students select and the number of tries they need to complete an exercise. If these variables vary, then the learning paths of individual students differ. Our study aims to investigate the learning material in an authentic setting, so experimental set-ups are not feasible. We therefore opted to log student interaction with the learning material by storing the <u>traces</u> on the e-learning's webserver without the need to install software on the student's computer. Student interactions with the web-server were therefore logged, but it was technically not feasible to log student interactions with other applications, such as informative websites.

5.3 Development

The instruments that are needed for the evaluation instrument are summed up in Table 5 on page 65. This section describes the development of the instruments.

Learning outcomes were measured in two ways. One method comprised the inclusion of a pre- and post-test to the adaptive e-learning material to measure students' achievement of the material's learning goals. These pre- and post-test were taken using a computer. The developer of the adaptive e-learning material wrote the test exercises. For the PCR Tutor, the exercises from the pre- and post-test only differed in the DNA sequence, the formulation and scoring of the exercises was the same (Figure 9 on page 55). Scoring was performed with an answer template. The exercises belong to the application learning goal (which is the main learning goal) of the tutor. In the other method end-of-course exam scores for the relevant subject were compared to the overall score of the exam to yield information on relative learning success.

Student responses to the questionnaire yield data about the used problem-solving strategies, appreciation, motivation, used information sources and demographic data. Items for the scales were formulated for an online questionnaire (Figure 10 on pages 68-71). Guidelines were followed to obtain concrete answerable and neutral items [57]. We included the questionnaire into the adaptive e-learning material to simplify data analysis and to ensure high response rates. Answers to the questionnaire are logged and connected to the student's User ID. This way we couple relate the questionnaire responses to the traces. The questionnaire is presented to students when they have finished the exercises. This raises some issues regarding the measured motivation of students. In the ideal case, motivation is measured before from the intervention as a time independent variable. The reason to measure the motivation directly after the intervention is partly practical (to circumvent the need for two questionnaires), and partly because the motivation is determined by the appreciation of students for the adaptive e-learning material, the subject and computer-based instruction. It is possible to measure this appreciation beforehand, but students have none or very little experience with the adaptive e-learning material and subject. We therefore decided to measure motivation afterwards, although it should be regarded as an independent variable.

To improve this module and to gain insight in the effect of digital learning material, we kindly request you to share your experiences with this module. The answers you give will be processed confidentially. Any published data will only include statements about groups, and hence can't be traced back to individuals.

Did you finish the module?:

○ Yes

○ No

How long did you spend on this module?:

[ ] minutes

Strategy used by students

Please indicate how often you used the methods below to complete the exercises in this module:

	Never	Seldom	Sometimes	Often	Always
I studied relevant theory on the exercise before working on it. I then selected the best answer.	○	○	○	○	○
I read the exercise carefully and selected the best answer.	○	○	○	○	○
I read the exercise and took a guess at first. Then I read the feedback and tried to select the right answer.	○	○	○	○	○
I didn't read the exercise and guessed an answer.	○	○	○	○	○
I talked to my fellow students, discussing what the best answer would be and then chose that answer.	○	○	○	○	○
I asked the teacher to explain the exercise before submitting an answer.	○	○	○	○	○

Please indicate how often you used the methods below to answer the exercises in this module:

Direct student input/Adaptivity

Please indicate to what extend you agree with the following statements:

	Strongly disagree	Disagree somewhat	Neutral	Agree somewhat	Strongly agree
I understood the differences between the step sizes.	○	○	○	○	○
I liked the fact that I could choose the step size between the exercises.	○	○	○	○	○
Being able to choose the choice for step size was pointless.	○	○	○	○	○

Please indicate how you used the possibility to choose the step size:

	Never	Seldom	Sometimes	Often	Always
I consciously chose the step size.	○	○	○	○	○
I chose small steps.	○	○	○	○	○
I chose big steps.	○	○	○	○	○
I chose medium steps.	○	○	○	○	○
At the end of the module, I chose more big steps than small steps.	○	○	○	○	○

Feedback

Please share your experience with the feedback that was provided:

	Never	Seldom	Sometimes	Often	Always
I read the feedback on incorrect answers.	○	○	○	○	○
I read the feedback on correct answers.	○	○	○	○	○
The feedback helped me to give the right answer.	○	○	○	○	○
I understood the feedback that was given.	○	○	○	○	○
The feedback made it clear where I had made mistakes.	○	○	○	○	○
The feedback on the incorrect answers was useful.	○	○	○	○	○
The feedback on the correct answers was useful.	○	○	○	○	○
The feedback should have been more extensive.	○	○	○	○	○

Library

Please share your experience with the documentation section.:

	Never	Seldom	Sometimes	Often	Always
I used the information in the online library.	○	○	○	○	○
I used the information sources when the feedback directed me there.	○	○	○	○	○
I used the Internet to find additional information.	○	○	○	○	○
I needed more information than is available in the online library to complete the exercises.	○	○	○	○	○
The information in the online library was clear.	○	○	○	○	○
The information in the online library helped me to complete the exercises.	○	○	○	○	○

▾Indirect student input/Efficiency

Please indicate to what extend you agree with the following statements:

	Strongly disagree	Disagree somewhat	Neutral	Agree somewhat	Strongly agree
I would have liked more exercises.	○	○	○	○	○
I was given too many similar exercises.	○	○	○	○	○
I need extra training options to practice with designing PCR primers in addition to this module.	○	○	○	○	○
Having completed this module I feel I can answer an exam question on PCR Primer Design correctly.	○	○	○	○	○
Before I began the module, my knowledge on PCR Primer Design was very limited.	○	○	○	○	○

▾ Comprehensibility

Please indicate to what extend you agree with the following statements:

	Strongly disagree	Disagree somewhat	Neutral	Agree somewhat	Strongly agree
The language used in the exercises in the module was clear.	○	○	○	○	○
I had difficulty understanding the English used in this module.	○	○	○	○	○
This module taught me a lot of new things about PCR Primer Design.	○	○	○	○	○
The exercises were too difficult.	○	○	○	○	○
I had enough prior knowledge to follow this module.	○	○	○	○	○
I understood the introductory film. (if you did not watch this film, skip this question)	○	○	○	○	○

▾ Appreciation

Please indicate to what extend you agree with the following statements:

	Strongly disagree	Disagree somewhat	Neutral	Agree somewhat	Strongly agree
Using computer-based modules is a nicer way of studying the theory than completing exercises on paper.	○	○	○	○	○
I would like to follow modules like the PCR Primer Design module on a range of subjects and topics.	○	○	○	○	○
This module was boring.	○	○	○	○	○
In general, I prefer using computer-based learning material to traditional learning material.	○	○	○	○	○
This module motivated me to think about PCR Primer Design.	○	○	○	○	○
I find PCR Primer Design an interesting subject.	○	○	○	○	○
The module took up too much of my time.	○	○	○	○	○
This module made learning about PCR Primer Design more interesting.	○	○	○	○	○
I like working with computers as part of my studies.	○	○	○	○	○
Understanding PCR Primer Design is important for my future career.	○	○	○	○	○
I think having a good understanding of PCR Primer Design is important for my studies.	○	○	○	○	○
I enjoyed this module.	○	○	○	○	○
I preferred this module on PCR Primer Design to traditional learning material.	○	○	○	○	○
This module challenged me.	○	○	○	○	○
Learning about designing PCR primers is useful.	○	○	○	○	○

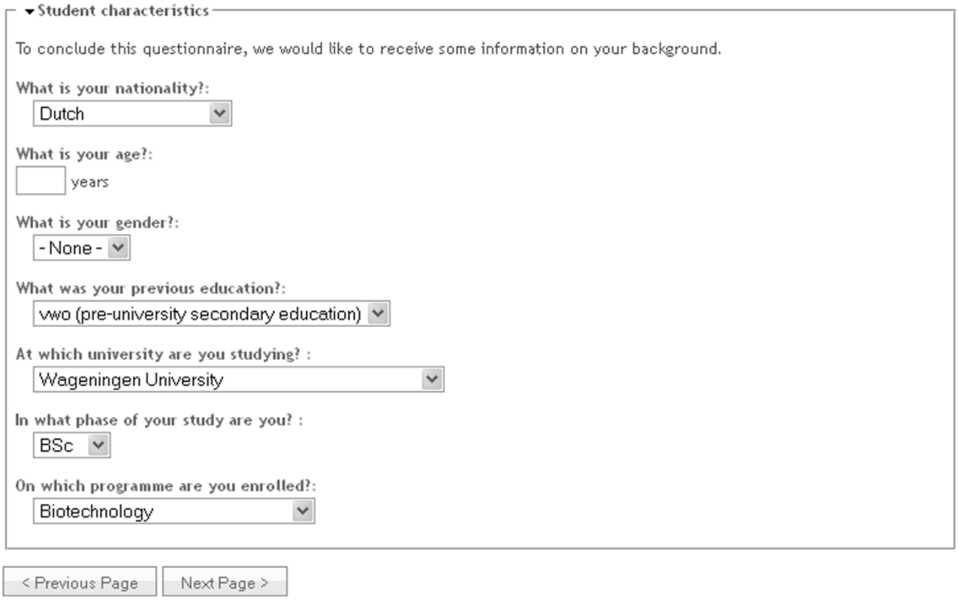


Figure 10. Screenshots of the online questionnaire that was added to the PCR Tutor

Traces are the logged interactions of students with the adaptive e-learning material. The system assigns a unique ID to each student. This User ID is a serial number which contains no references to the student's name to protect privacy of the participant. The logged actions are:

- The step size a student chose
- The exercise selected by the system
- The answers a student submitted and the submission time
- The submission of a correct answer
- The student level for each learning objective after completing an exercise
- Resetting when students chose to start over again (optional)

From these data we can deduct the number of tries that students need to complete an exercise, the number of exercises that students needed to finish, the variation in step size and the time they needed to finish the module.

5.4 Quality

The quality of the developed instruments is discussed by describing their validity and reliability. The reliability is the consistency of a measurement, *i.e.* the degree to which an instrument measures the same data each time it is used under the same conditions with the same subjects. Validity is the extent to which an instrument measures what it is supposed to measure. We take a digital thermometer as an example to explain these terms. If the thermometer consistently measures the temperature 2 degrees too high, it is said to be reliable but not valid. If the thermometer measures the temperature sometimes too high and sometimes too low, it is said to be unreliable.

The validity of the pre- and post-test was determined using expert validity. Two experienced teachers in the field commented on the tests and their suggestions were implemented. The reliability of the scoring of pre- and post-test was tested for internal consistency by having a second rater and comparing the scores. The scores of the two raters corresponded for 100%, so the reliability of the pre- and post-test was good. The reliability and validity of the end-of-course exam, which are part of the regular curriculum, were not measured.

The questionnaire was validated by having it checked by an expert in the field of questionnaire development. Suggestions for improvement were implemented and after that, a pilot evaluation with the questionnaire was conducted. Students participating in this pilot were interviewed to identify their interpretation of the items, since small changes in the wording of items can have big consequences [58]. Ambiguous items were revised. Interpretation of self-regulation from the traces is difficult. The choice that a student made is logged, but the reason to do so, was not. The reliability of the motivation subscales, calculated as Cronbach's alpha, was measured (Table 13 on page 104). An alpha value above 0.7 is generally adopted as sufficient reliability. The reliability of students' self-reports was measured by comparing self-reported with corresponding traces, such as the time needed to finish the module and the step size choices they made [59]. The self-reports and the traces correlate very well, so we assume the self-reports to be reliable (Chapter 8).

5.5 Implementation and use

The evaluation instrument was developed as part of the research described in this thesis. The studies described in the following chapters therefore use increasingly mature versions of the evaluation instrument. The developed questionnaire and traces were used to evaluate the Enzyme Kinetics Tutor (EKT) (Chapter 7) and PCR Tutor (Chapter 8). End-of course exams were used to assess student achievement for the Cell Growth Kinetics Tutor (Chapter 6) and the EKT [5]. The pre- and post-tests were used to measure student achievement for the PCR Tutor (Chapter 4).

Chapter 6
Evaluation of adaptive e-learning material about cell growth kinetics[4]

6.1 Introduction

The various university exchange programs have led to more differentiation in levels of student knowledge at the beginning of a course. For a teacher it is not desirable to teach concepts that are not known to some students whereas other students do know these concepts and are bored and not motivated. To address this problem of different levels of prior knowledge it is preferred to use learning material that presents the theory to the student in a differentiated way. One way to accomplish differentiation is by using e-learning. E-learning is increasingly being used in university education [60, 61]. E-learning capable to offer theory in a differentiated way to students is called adaptive e-learning. Adaptive e-learning can be of help to teach a heterogeneous group of students by adapting to the knowledge level of individual students [23, 40]. Several groups have focussed on the development of adaptive e-learning [62-66]. The systems to create adaptive e-learning are categorised by Brusilovsky and Peylo [12]. Systems that allow access using the Internet are called adaptive and intelligent Web-based educational systems and systems used to let the student actively practise with concepts are called intelligent tutoring systems. These terms overlap and the system investigated in this thesis belongs to both categories; the term adaptive e-learning system is chosen to identify the system.

E-learning can adapt to the student by collecting information about the student and then to build a model [67], also called student model [68, 69] or learner model [20, 70]. We interpret the learner model as a model of the student based on the information that the system has acquired. This information can be *static*, i.e., it does not change during the learning activity (e.g., the student’s gender, preference

[4] Based on: J. van Seters, M. Ossevoort, M. Goedhart & J. Tramper. Accommodating the difference in students' prior knowledge of cell growth kinetics. Electronic Journal of Biotechnology, 2011. **14**(2) http://dx.doi.org/10.2225/vol14-issue2-fulltext-2

for video or audio) or *dynamic*, i.e., the information changes during the learning activity (e.g., the student's knowledge level).

The collaboration between Wageningen University, the Netherlands and China Agricultural University involved the inflow of undergraduate students from China in biotechnology and food technology programs at Wageningen University. The exchange students followed the first part of the study program in China and came to the Netherlands to continue in the second year of the regular undergraduate program. So, from the second year onwards regular and exchange students followed the study program together, which meant that a heterogeneous group of students thus had to be educated in the second and third year of the study program. Instructors experienced problems when giving their lectures because of the differences in the levels of students' prior knowledge. The possibility to use adaptive e-learning was seized, and adaptive e-learning material to teach cell growth kinetics was developed for use in a course on process engineering. This study describes the development and advantages of using this adaptive e-learning material at the beginning of the course to tackle the problem of educating a heterogeneous group of students in an undergraduate course on process engineering.

6.1.1 The adaptive e-learning system

The adaptive e-learning system, called Proteus, used to make the adaptive e-learning material was developed by Sessink et al. [47] and is decribed in Chapter 3.

Three parameters contribute to the adaptive feature of the material. Two are system-driven, namely the distribution of credit points after incorrect answers and the selection of the next exercise. The other is student-driven, namely the choice of step size for the next exercise. The use of these three parameters makes the system adaptive and allows for differentiated learning paths.

6.1.2 Content of the adaptive e-learning material

In order to teach the basic knowledge needed for bioreactor design, which is part of the course on process engineering, adaptive e-learning material called the Cell Growth Kinetics Tutor (CGKT) was designed. It was made using the adaptive e-learning system Proteus, which was described in detail in Chapter 3. By working with the CGKT students learn to set up a general mass balance over a general bioreactor. From that, they learn to derive the basic equations for batch and continuous stirred tank reactor. They learn the concepts of specific growth rate μ, Monod (K_s, μ_{max}), biomass yield coefficient y_{xs}, maintenance coefficient m_s, and by specifying mass (substrate, biomass) and units (*kg, m, s,* etc.), learn to derive the equations needed to calculate desired reactor volumes, residence times, conversions, etc. Thus, the CGKT provides knowledge and understanding by means of basic bioreactor applications.

The tutor contains exercises, including feedback, an online documentation section (library), and annotated credits for the exercises, were written by a researcher in the field of biotechnology education. The feedback is adaptive and consists of 'answer until correct' and 'elaborated' types of feedback [35]. After use by the students the content was improved in several revision cycles. The CGKT contains different types of exercises, such as multiple choice questions, calculation exercises, and exercises to design an equation (Figure 11).

The CGKT is freely available for use in educational settings to teach the basics of cell growth kinetics.

Preliminary results from the CGKT have been presented before [4], and offer promising perspectives to teach heterogeneous groups of students. Students found the use of the CGKT challenging, useful, and were generally positive about the CGKT, regardless of their background. In this study, the opinion of the students about the use of the CGKT was analysed.

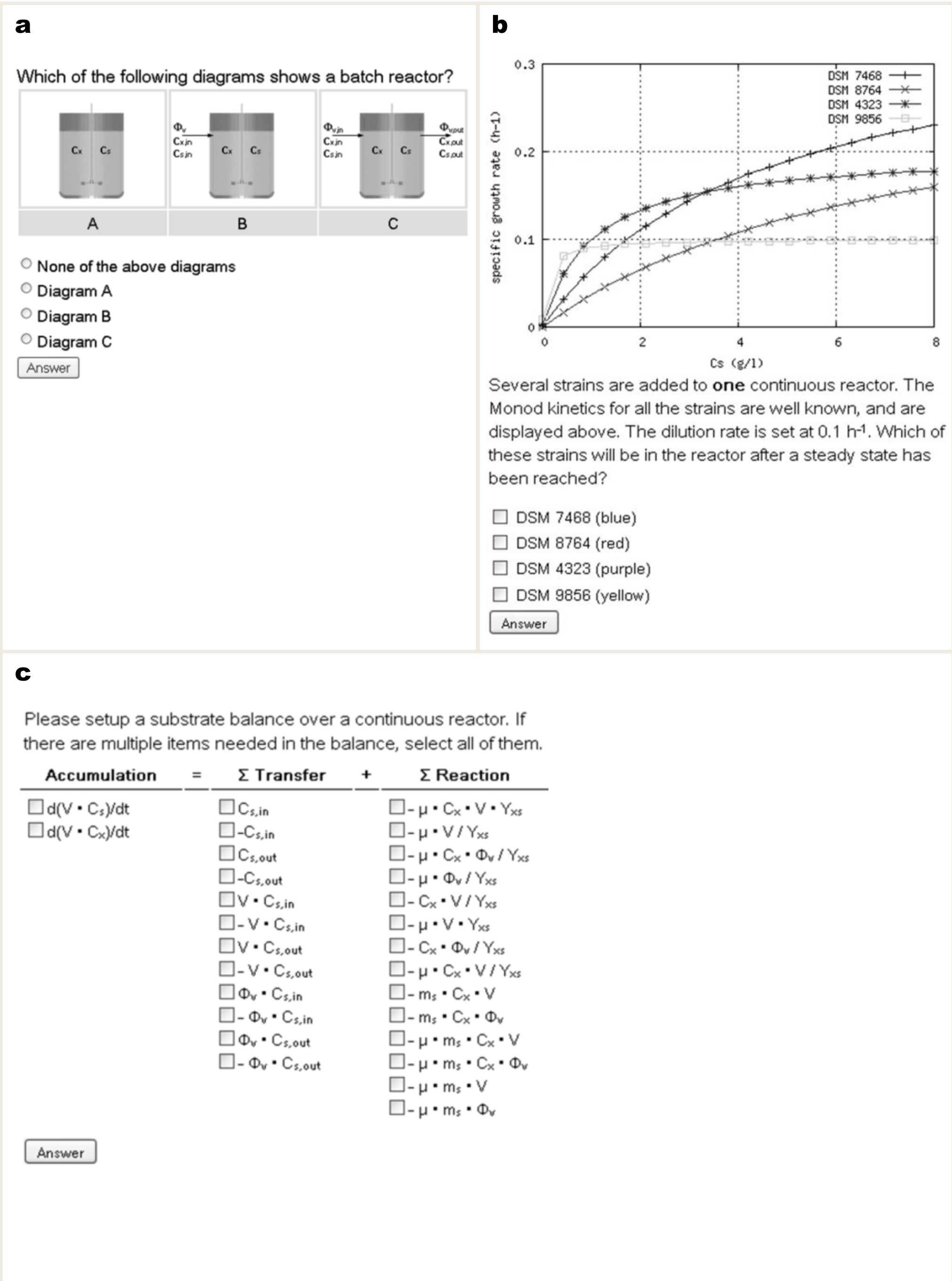


Figure 11. Screenshots from the Cell Growth Kinetics Tutor showing examples of different types of exercises: a) multiple choice, b) multiple answer, and c) equation design

6.1.3 Aim of this study

The aim of this study was to discover if the CGKT at the beginning of the course could give students with different prior education the same basic level of knowledge needed to comprehend the subsequent lectures and pass the exam. The three subsequent research questions were:

1. Do students with different levels of prior education perform equally well on the topic of cell growth kinetics after introduction of CGKT?
2. Do students appreciate using the CGKT to gain knowledge about cell growth kinetics?
3. Do students follow different learning paths to finish the CGKT?

6.2 Materials and methods

6.2.1 Participants

Participants in this study were regular and exchange students in the second year of the biotechnology or food technology programs at Wageningen University, the Netherlands. All students were following a course 'Introduction to process engineering'. The exchange students had followed a two-year preparation program in China, which is expected to differ from the first-year program that the regular students followed. This study covered three successive years (cohorts). The numbers of students that participated in the study per cohort is given in Table 6.

Table 6. Overview of the number of students that were analysed in the study

Cohort	Regular group	Exchange group
1	54	12
2	22	37
3	38	23

6.2.2 Context of the experiment

The students from cohort 1 followed the course 'Introduction to process engineering' without the CGKT. This course consisted of lectures in which the instructor explains the subject matter, and seminars in which the student practise the subject matter by making exercises. The students from cohorts 2 and 3 followed the course with the CGKT added, which was introduced by the instructor during the first lecture on bioreactor design. The students worked with the CGKT during the subsequent seminar of two hours. The instructor and several assistants were available to help students with the material. The students were allowed to finish at home if necessary. At the end of the course the students' knowledge was tested during an exam, containing one CGKT-related question.

6.2.3 Data collection

The data that were needed to answer the three research questions were collected from exam scores from all students, and the student data and responses to a questionnaire logged from the students of cohorts 2 and 3. The exam scores for the CGKT-related question were obtained from the end-of-course exams. The student data contain the answers students submitted to the exercises of the CGKT. From the student data it is possible to deduce how many exercises an individual student needed to finish the CGKT.

To enhance learning it is important that students are motivated by the material they use. To discover if students appreciated the CGKT, we asked them to fill in a questionnaire after finishing. This questionnaire consisted of open-ended and Likert-scale items. The items from the questionnaire analysed in the study were '*This module is useful*', '*This module is fun*', '*This module challenged me*' and '*This module is motivating*'. Student could indicate on a five-point scale in how far they agreed with the statements. In addition, the course instructor was interviewed to give his opinion about the adaptive e-learning material.

6.2.4 Data analysis

The data were filtered to include only the students relevant for this study: those who finished the CGKT and took the exam for the first time. The number of exercises that students needed to finish the CGKT was calculated.

The data from the regular and exchange student groups were compared in order to find differences between them using the parametric independent *t*-test or the non-parametric Mann-Whitney test. The statistical analysis was conducted using Statistical Package for the Social Sciences (SPSS) for Windows (release 17.0.3.2007). A significance level of $p < .05$ was used.

6.3 Results

6.3.1 Analysis of the exam scores

The differences in scores to the CGKT-related question of the exam between the two student groups were measured using both parametric and non-parametric tests (Table 7).

Table 7. Comparison of exam scores

Cohort	CGKT?	Mean score		Difference
		Regular group	Exchange group	
1	No	4.0 (N= 54)	0.8 (N= 12)	3.2[a]
2	Yes	4.8 (N=22)	5.4 (N=37)	0.6
3	Yes	5.0 (N=38)	3.6 (N=23)	1.4[a]

[a] *significant at .05 level*

The results from Table 7 show that before introduction of the CGKT the difference in mean exam scores for the CGKT-related question between the two student groups is large (cohort 1). After introduction of the CGKT the differences are smaller (cohort 3) or even absent (cohort 2).

6.3.2 Analysis of the questionnaire

Four Likert-scale items on appreciation were included in the questionnaire, and the answers to these items were combined into one indicator of appreciation by averaging them. The results are given in Table 8.

Table 8. Means of the responses to Likert-scale questions in the questionnaire

Item	Cohort 2		Cohort 3	
	Regular	Exchange	Regular	Exchange
This module is useful	4.4	4.0	4.2	4.7
This module is fun	3.1	3.6	2.7	3.1
This module challenged me	3.8	3.8	3.9	4.1
This module is motivating	3.4	3.8	3.6	4.1
Appreciation mean	3.7	3.8	3.6	3.9

The appreciation mean indicates that all student groups appreciated the use of the CGKT ($M = 3.6\text{-}3.9$). There is no significant difference in appreciation between regular and exchange students ($p > 0.05$).

In an open question the students were asked to write down their opinion on the CGKT. The responses illustrate the positive opinion of the students on the

CGKT. Students for instance wrote: *'The material can help me to learn and understand the equations better than before', 'At first I thought it would be very very hard for me to finish it, because I didn't get enough information from the instructor. However when I started it I found I could get most information from the digital library and it seems more interesting and challenging to find the right answer and get a high grade. I really like the material!', 'The explanation at the end of the exercise why the answer was correct is very clear.'* and *'the hints are important and clear enough to give me some information when I made mistakes'*.

Students also encountered problems using the CGKT. They found the scoring system inconsistent and unclear: '*I think the penalty for a wrong answer could use some adjustment*' and '*the negative points you get when you make mistakes should be changed*'. They also indicated that more information was needed to find the right answer: '*I want to know more about the explanation of the questions*' and '*I do think there could be more explanation in the library or more extensive hints*'

6.3.3 Analysis of the traces

The adaptivity of the CGKT is system- and student-driven: the selection of exercises by the system according to the performance of the individual student as recorded in the learner model is system-driven; and the selection for small, medium and big steps is student-driven. As a result, the number of exercises students need to finish the module can vary. The comparison of the two student groups in cohorts 2 and 3 shows no difference in number of exercises needed between both groups ($p > 0.05$). However, the number of exercises needed to finish the module varies a lot within the groups (Table 9).

Table 9. Mean and range of the number of exercises needed to finish the module

	Cohort 2		Cohort 3	
	Mean (SD)	**Range**	**Mean (SD)**	**Range**
Regular group	49.8 (*12.0*)	23-69	54.5 (*14.8*)	27-86
Exchange group	52.1 (*12.7*)	26-82	54.6 (*15.5*)	27-82

6.3.4 Teaching experiences

Before the CGKT was used, the course instructor experienced problems when teaching the two student groups (cohort 1). He received many questions about basic concepts during the lecture and seminar. The explanation of these basic concepts took too much of the time that was otherwise spent dealing with more complex concepts. After the introduction of the CGKT the problems were to a large extent solved. Since the students work with the CGKT before attending lectures about the complex concepts, they understand these lectures much better. The questions that the instructor received in the seminar were more advanced. In his opinion, the CGKT helped students to understand basic concepts, and basic mistakes they made were often covered in the feedback on the exercises.

6.4 Discussion

The use of adaptive e-learning is one way to overcome the problem of differences in levels of prior knowledge between students entering a course. Our study indicates that the CGKT at the beginning of the course provided students of varying levels of prior education with the basic level of knowledge needed to follow the subsequent lectures and pass the exam. Furthermore, the students liked using the CGKT, which increased their motivation.

The system that we describe in this thesis, Proteus, collects student specific dynamic data. The learning activity is adapted to the student on the basis of these data. Most adaptive systems described so far only collect static student data [65, 71, 72], so that we believe that using Proteus is innovative in this respect.

Unexpectedly, we did not find a difference between the regular and exchange students in the average number of exercises needed to finish the module. However, there is a large within-group variety in the number of exercises needed to finish the module. Thus, it seems that the adaptive feature of the CGKT is exploited by both student groups, regardless of their background. A possible explanation for this finding is that student groups are always heterogeneous. Individuals differ in their learning strategies, their motivation to learn, and their capacities. Personalized instruction is therefore always beneficial. Since the development of adaptive e-learning material is costly it is important to know which student characteristics are of most importance to take into account when considering the use of adaptive e-learning material. Chapter 8 elaborates on this recommendation.

The results from the open-ended and Likert-scale questions show that students are very positive about using this material. We therefore recommend to continue using this CGKT and initiate the development of adaptive e-learning material on other topics.

The responses to the questionnaires also gave good suggestions for improvements, and we already implemented some of these. For example, the presentation of the scoring system has been changed to conform to students' expectations, and the feedback to incorrect answers has been expanded.

The combination of the different learning paths followed by students, the decrease in variation in exam scores, and the instructor's observations lead us to the conclusion that adaptive e-learning material can be used to provide students with different levels of prior education the same basic level of knowledge on cell growth kinetics so that they are be able to follow the subsequent lectures and pass the exam.

Although designed to fit the context of the course 'Introduction to Process Engineering' the adaptive e-learning material can easily be used as part of other courses or at other universities since it is web-based. This has already been done at the University of Technology in Graz, Austria. Furthermore, the adaptive e-learning system can contain other content as well, thus providing plenty of possibilities for creating new adaptive e-learning material.

6.5 Concluding remarks

Our study shows that the CGKT at the beginning of the course did give students of varying levels of prior education the basic level of knowledge needed to follow the subsequent lectures and pass the exam. We also report a positive attitude of the students towards the CGKT.

We advise educators who are confronted with students that have different prior knowledge to start their course with learning materials that offer the required knowledge in a differentiated manner. The freely available system Proteus facilitates such a smooth implementation since it only requires Internet access and an Internet browser to function. This system allows teachers to integrate questions and resources, which they think are suitable for the concepts they want to teach using adaptive e-learning material. The number and kind of questions can easily be adapted. But, teachers have to take care when designing the exercises since the learning effectiveness of the material relies heavily on the quality of the exercises.

In addition, good ICT arrangements have to be made to ensure a bug-free implementation of the e-learning.

The CGKT described in this study allows for self-regulated learning by letting students select the step size for the exercises. At the end, all students have to achieve the same pre-defined learning objectives to be able to finish the CGKT. The question remains what the exact role of self-regulated learning is when using adaptive e-learning material. It is interesting to investigate in more detail the impact of the step-size that students choose to go through the material. It is for example known that the learning strategy of students is also related to their gender. In addition, the prior knowledge of the students and the learning effect of the adaptive e-learning material can be directly investigated by adding a pre- and post-test to the adaptive e-learning material. Chapter 8 elaborates on these suggestions.

Chapter 7
Evaluation of adaptive e-learning material about enzyme kinetics[5]

7.1 Introduction

Trained scientists in the field of biochemical engineering are required for the expected transition from oil-based to biomass-based production of chemicals and fuels. A key process in biomass-based technology is the conversion of substrates using enzymes as catalysts. Subjects that deal with the conversion of substrates into fermentable compounds for industrial purposes, like enzyme kinetics, therefore have to be part of biochemical courses at colleges and universities. However, enzyme kinetics is a difficult subject for students to master [73, 74] and hence it requires a substantial effort on the part of students to study the subject. To make this effort students have to be motivated, but this may be difficult since the relevance of the subject is not always immediately clear to students. One way to increase motivation is to let students work actively with the subject matter [75]. Letting students practice with given tasks is a widely used way to achieve active participation. Since it is difficult to learn enzyme kinetics, letting students practice individually may put a heavy load on the teacher, since the teacher has to give feedback individually. The use of computers when teaching enzyme kinetics could offer a solution. On the one hand, students will use innovative learning materials to actively participate in the course. On the other hand, the load for the teacher is lower compared to traditional seminars because the computer can provide automatic feedback.

An additional way to increase student motivation is by adapting the level of the learning material [18]. This way students get all the instruction they need to understand a subject, but do not get redundant training. Adaptive e-learning systems can offer the concepts which have to be learned in a personalized way [18].

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[5] Based on: J.R. van Seters, F.C. Lanfermeijer, H. van der Schaaf, J. Tramper, M.J. Goedhart, M.A. Ossevoort, A Web-Based Adaptive Tutor for Enzyme Kinetics, Journal of Chemical Education (*under review*)

Adaptive tutors stimulate active participation and offer personalized practice. Students follow different learning paths to reach the required learning goals [22]. The use of computers to teach enzyme kinetics is not new. Different groups have reported the use of e-learning in biochemistry courses [76-82]. However, no literature is available on the use of an adaptive tutor to provide personalized education about enzyme kinetics.

To meet the demand for personalized education in enzyme kinetics in higher education, we developed adaptive e-learning material to teach basic enzyme kinetics, called the Enzyme Kinetics Tutor (EKT). Preliminary results show that the EKT can be used in undergraduate life science courses [5]. The reported results show that the EKT has a positive learning effect on undergraduate students. With this paper we build on the presented preliminary results and elaborate on the content of the developed EKT. The features that students use to personalize their learning are investigated in more detail.

In this paper, we describe the design and evaluation of the EKT by means of the following research questions:

1. Which features of the EKT do students use to personalize their learning?
2. What is the students' perception of the EKT?

7.2 Materials and methods

7.2.1 Development of the adaptive tutor

The EKT was constructed using the adaptive e-learning system Proteus [47]. The EKT provides exercises with feedback about enzyme kinetics. The material has been tested and revised in several rounds to yield the EKT used in this study. Most of the exercises were developed by researchers in the field of enzyme kinetics in cooperation with the lecturers who would be implementing the EKT in their courses. The EKT offers personalized learning in three ways: by varying the number of exercises that students have to make, by providing tailored feedback, and by letting students choose the pace at which they go through the material.

The EKT deals with topics that are important in enzyme kinetics [73]. The topics are ordered in four categories, and ninety exercises were designed to cover the topics; one exercise can belong to one or more categories. The four categories are: basic concepts of Michaelis–Menten kinetics, kinetics of inhibition of enzymes, linearization of Michaelis–Menten kinetics curves, and units used in Michaelis–Menten kinetics (Table 10).

Table 10. The four categories of the enzyme kinetics tutor (EKT) with associated topics

Category	Topics
Basic concepts of enzyme kinetics (32 exercises)	V_{max}, K_m, turnover number and their relation to substrate concentration [S] Interpretation of V, [S]-diagrams and [S], t-diagrams
Inhibition (34 exercises)	Irreversible inhibition Competitive inhibition Uncompetitive inhibition Noncompetitive inhibition The effects inhibitors have on the reaction rate and substrate affinity of enzymes Interpretation of experimental dataset reaction rates associated with different substrate concentrations Interpretation of Lineweaver-Burk plots with different inhibitors The inhibitor constant K_i
Linearization (23 exercises)	Construction and interpretation of Lineweaver-Burk plots Construction and interpretation and creation of Eadie-Hofstee plots
Units (8 exercises)	Units associated with V, V_{max}, k_{cat}, K_m, and K_i The difference between unit and katal

Four different types of exercises for the EKT were designed: multiple choice questions, multiple answer questions, drag and drop exercises, and open questions. Figure 12 on the next page shows screenshots from examples of each of the categories and exercise-types present in the EKT.

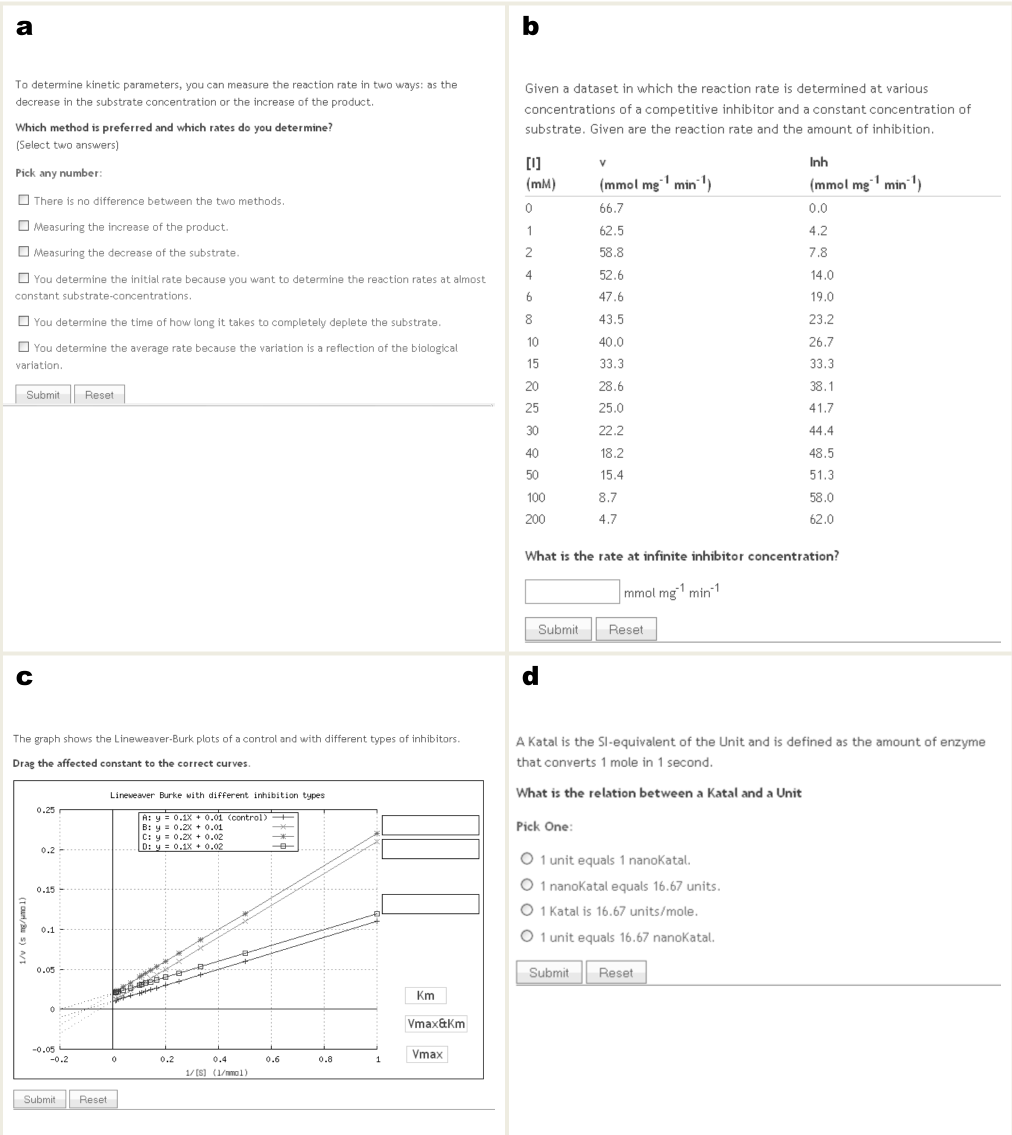

Figure 12. Screenshots from the Enzyme Kinetics Tutor to illustrate exercises from the different categories: basic concepts of Michaelis–Menten kinetics (a), kinetics of inhibition of enzymes (b), linearization of Michaelis–Menten kinetics curves (c) and units used in Michaelis–Menten kinetics (d). The screenshots also illustrate different types of exercises present: multiple answer (a), open question (b), drag and drop (c) and multiple choice (d) exercises.

7.2.2 Student interaction with the EKT

When students start working with the EKT, they can select the pace at which they go through the material. They can do so by choosing between a simple exercise and a more complicated exercise (small, medium of big step size). The topics of the exercises are selected randomly, so the exercise deals with basic concepts, inhibition, linearization, units, or a combination of these. A student works on the exercise until the right answer has been given. Students must attain a preset threshold level for each category to complete the EKT. Students come to this level by submitting correct answers. More tries result in smaller advances to the threshold level. When an exercise is finished, the student can choose again between the different step sizes, and the system then presents another exercise of one of the four categories to the student.

If an incorrect answer has been given, feedback is provided to help the student to solve the exercise. The feedback consists of general hints, specific explanations about why an answer is correct or incorrect, and references to relevant sections from the textbook used in the course. To increase the learning effect of the exercises, elaborated feedback to correct answers was included. This feedback presents additional information to explain why the answer was correct [35]. The feedback given for incorrect answers aims to provide information that is important to complete the exercise, but does not immediately offer the correct solution, an approach called informative tutoring feedback [83].

7.2.3 Implementation in an undergraduate biochemistry course

Results from a pilot study show that the EKT is appropriate for use by undergraduate students at the end of their second year [5]. For this study, the EKT was implemented in an undergraduate course taught by the biochemistry department of Wageningen University. The participants were forty-eight life science students, who attended the course during the end of the second year of their three-year undergraduate program. The EKT was used in a computer room during a period of four hours. The time students ought to need to finish the EKT was estimated to be approximately four hours. All students worked individually but were allowed to confer with their peers. The teacher was available during the sessions to answer questions. The students could finish the module at home if necessary. After finishing with the EKT, the students were asked to complete a questionnaire to measure their motivation.

7.2.4 Data sources and analysis

Two data sources were used in this study: responses to a questionnaire and the actions of the students when working with the EKT (traces).

The questionnaire contains items measuring perceived motivation of the students, comprehensibility of the EKT, student perception about the adaptivity of the EKT, and the use of feedback. All items were scored on Likert-scales from 1 to 5. The mean score of all students per item was calculated. The items concerning motivation comprised three scales: motivation for computer-based education, motivation to use the EKT, and intrinsic motivation for the subject. The reliability of these scales was measured in advance and Cronbach's alpha values were all above 0.7.

The traces on the web server consists of the step sizes that students chose, the exercises that were selected by the system, and the answers students submitted. The responses to the questionnaires and the students' traces were analyzed using SPSS/PASW Statistics for Windows version 17 (release 17.0.3).

7.3 Results and discussion

7.3.1 Personalized learning

The EKT offers personalization in three ways. The first way to determine personalized learning deals with the number of exercises that students make. The amount of exercises students needed to finish the EKT varied between 23 and 126 (traces). Some students thus had to make some exercises several times. In the questionnaire students also reported that they spent an average of 3 hours and 40 minutes working on the EKT, ranging from 2 to 10 hours. These results indicate that the EKT on average meets the set criterion to take around 4 hours to finish, but 25% of the students needed more time. The variation in time and in the number of exercises that students needed indicates the presence of personalized learning.

The second way to offer personalization concerns the presentation of tailored feedback. The use of this feedback by the students is analyzed with Likert scores in the questionnaire (Table 11). The results show that students always read the feedback on incorrect answers ($M = 4.7$) and often read the feedback on correct answers ($M = 3.7$). The feedback on the incorrect and correct answers were often ($M = 3.6$) and sometimes ($M = 3.1$) perceived as useful. So, these data suggest that the feedback is well read and well received and often helped students to give the right answer ($M = 3.6$). It was expected that students often read the feedback on incorrect answers. The feedback on the correct answers is however also read, maximizing the learning effect students can get from the EKT [35].

Table 11 Student responses (n=48) to questionnaire items about the use of feedback in the EKT. Answer options were: 1=Never | 2=Seldom | 3=Sometimes | 4=Often | 5=Always

	Response Mean (SD)
I read the feedback on **incorrect** answers.	4.7 (0.5)
I read the feedback on **correct** answers.	3.7 (1.1)
The feedback helped me to give the right answer.	3.6 (0.7)
The feedback on the **incorrect** answers was useful.	3.6 (0.9)
The feedback on the **correct** answers was useful.	3.1 (0.8)

The traces were analyzed to obtain information about the way in which students chose the step sizes. We observed that all forty-eight students kept their step size constant for several exercises in a row. Some patterns were identified in the usage of the different step sizes. Fourteen students (29%) started with the EKT by taking small steps, and then switched to medium steps and subsequently to big steps. After increasing their step size, twelve of these fourteen students went back to a smaller step size. Seven students (15%) did not change the step size: they only chose big steps. There were no students who chose only small or medium steps. Ten students (21%) started by choosing big steps and then changed their step size to medium or small steps. Eight students (17%) started with medium steps and switched to big steps. The order in which individual students chose the step sizes to go through the EKT varies. This variation contributes to the personalization of education.

Two items from the questionnaire about the step size that students chose were analyzed. Twenty-seven (56%) students indicated that they chose the step size consciously in most cases. Twenty-one (44%) students indicated that they liked the possibility to choose the step size, 17% did not like it and the rest were neutral. The personalization feature was thus appreciated by most students.

7.3.2 Student perception

The students' responses from the questionnaire are summarized in Table 12. The students stated that the language used in the EKT was clear (M = 4.2). Furthermore, they stated that the EKT taught them a lot of new things about enzyme kinetics (*M* = 3.8), but that the exercises were difficult (*M* = 3.5). Students' appreciation of the EKT was about neutral (*M* = of 2.9 on material motivation scale). Students appreciated the use of e-learning (*M* = 3.3 on computer-based education scale) and were motivated by the topic enzyme kinetics (*M* = 3.7 on subject motivation scale) (Table 12). The students' overall perception of their usage of the EKT measured by the questionnaire was positive.

Table 12 Student responses (n=48) to questionnaire items about comprehensibility of the EKT and student motivation. Answer options were: 1=Strongly disagree | 2=Disagree somewhat | 3=Neutral | 4=Agree somewhat | 5=Strongly agree

	Mean
Did students understand the English language used in the EKT?	
The language used in the exercises in the material was clear.	4.2 (0.5)
Did the EKT link up with the students' prior knowledge on the subject?	
This material taught me a lot of new things about enzyme kinetics.	3.8 (0.9)
The exercises were too difficult.	3.5 (0.9)
Did the students like the EKT? (material motivation scale)	2.9 (0.8)
Do the students like computer-based materials? (computer-based education scale)	3.3 (0.7)
Were students motivated by the subject/content of the material? (subject motivation scale)	3.7 (0.7)

7.3.3 Conclusion

We developed a web-based adaptive tutor to offer personalized instruction about enzyme kinetics for undergraduate biochemistry education: the Enzyme Kinetics Tutor (EKT). The EKT consists of exercises for practicing with basic concepts, inhibition, linearization, and the units used in enzyme kinetics. The three ways in which the EKT provides personalized education were investigated. These three ways are: adaptation of the number of exercises, presentation of tailored feedback, and ability to choose the pace at which one goes through the EKT. Our findings show that individual students indeed vary in the number of exercises they do to finish the EKT. The feedback on both correct and incorrect answers is read and appreciated. Students vary in the order in which they choose the step sizes to go through the EKT. Most students often change the step size during the EKT. The perception of students about the EKT was positive.

7.3.4 Suggestions for further research

Further studies could elaborate on the use of adaptive e-learning systems to teach chemistry topics in a personalized manner. The influence of student characteristics on the step sizes that they choose is for instance not investigated so far. The way students reflect on their own learning process while choosing step sizes can also be studied, e.g. whether students choose smaller steps after they gave many incorrect answers.

The tailored feedback that the EKT provides is supposed to decrease the amount of teacher assistance that students require. The EKT can be compared with traditional learning methods to test this hypothesis.

Research questions on students' conceptual knowledge can also very well be studied with the traces from students using the EKT. Analysis of the answers students give can provide valuable information on the way they learn enzyme kinetics.

Chapter 8
Self-regulated learning with adaptive e-learning[6]

8.1 Introduction

The variety in prior knowledge within student groups has increased since the Bachelor/Master system was introduced at European universities in order to increase student mobility within the EU. Students enrolling in Master's programmes come from different universities and their knowledge on specific topics varies. These varying backgrounds mean that university staff must provide the students with intensive tutoring. Time-consuming tutoring can be supported by adaptive e-learning material. Adaptive e-learning is suitable for teaching heterogeneous student populations in higher education [39], as it addresses the variety in the prior knowledge of students who enrol in a course. This gives students the opportunity to follow individual learning paths and meet their specific training needs [21].

Although several studies report on the benefits of adaptive e-learning (see for example [65, 84] and [85]), there is little to no empirical evidence that students do follow individual learning paths associated with their differences in prior knowledge. It is also unknown whether other student characteristics such as gender or intrinsic motivation influence their learning paths. Since the development costs of computer-based learning environments (CBLEs) are high, it is important to know under what circumstances and for which student groups adaptive e-learning is effective. This study provides empirical evidence to support educators' decisions. As such, it links up with questions raised by, for instance, Narciss, Proske and Koerndle [19] at the end of their manuscript: 'To date there has been little research into how individual differences in problem-solving strategies and styles, students' goals and motivational orientations and students' meta-cognitive skills contribute to differences in studying in web-based learning environments. … An ... issue for future research and practice is the question how

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[6] Based on: J.R. van Seters, M.A. Ossevoort, J. Tramper & M.J. Goedhart (2011) The influence of student characteristics on the use of adaptive e-learning material. Computers & Education. http://dx.doi.org/10.1016/j.compedu.2011.11.002

individual variables may determine the way students learn with web-based learning environments'. (p.1141)

In addition to these practical aims, research into computer-based learning can provide more insight into the ways students self-regulate their learning. As Winne [29] has pointed out: 'widespread use of CBLEs is vital to significantly accelerating the science of learning, particularly regarding self-regulated learning (SRL), and applying its findings in education.' (p.267) Azevedo and colleagues [86] claim that learning in hypermedia environments involves the use of numerous self-regulatory processes, such as planning, knowledge activation, metacognitive monitoring and regulation, and reflection. We think that this claim can be extended to other CBLEs and that adaptive e-learning material is a good tool to investigate SRL. This study therefore paid special attention to the SRL strategies that students adopt when using adaptive e-learning material.

8.1.1 The adaptive e-learning system

The adaptive e-learning system investigated in this research is called Proteus. It was developed by Sessink and colleagues [47] and used by van Seters and colleagues [22]. This computer-based system offers 'task or question modules to evaluate the learning process', which is a common approach according to Narciss and colleagues [19]. Adaptive e-learning systems are characterized based on what, where, why and how the systems can adapt [40]. Proteus adapts the amount of training and the content of feedback students receive [22] (the what). The adaptation of the amount of training and the feedback takes place during students' interaction with the e-learning system (the where). The amount of training is adapted to fulfil the needs of students who have little prior knowledge, but without imposing too much repetition on students who have more prior knowledge. The content of the feedback is adapted to target specific mistakes that students make (the why). The system varies the number of exercises according to the answers students submit to exercises related to the same learning objective. In addition, to establish the second mode of personalization (the how), the system lets students choose the next exercise according to three levels of complexity.

The system thus offers a mixed form of regulation according to Boekaerts [41], in that 'students and teachers (in this case, the adaptive e-learning material) share the regulatory functions' (p.450). The system selects appropriate exercises with regard to the current knowledge level of the student (the learner model), as described in the literature on computerized adaptive tests [45]. To select appropriate exercises, the system compares the learner model to the content model. Based on the gap between these models, the system selects exercises that will fill this gap. The regulatory function directed by the students is the step size they select before doing an exercise. Students choose between a small, medium or big step for the next exercise. The step size relates to the progress students may make towards the target level: a big step may lead to significant progress, while a small step may only lead to limited progress. Before each exercise, students may adapt the step size, allowing them to reflect on their learning. This way of stimulating self-reflection is known as embedded direct intervention [19]. The exercises contain adaptive feedback as described above.

Students tend to adopt a ‘trial and error’ behavior in e-learning environments [19]. In our system, this will not help students. Exercises have multiple answer options, making it harder for students to guess the correct answer. In addition, students have to complete more exercises if they give many incorrect answers. This feature has two advantages: it gives students who have not mastered the content a lot of practice and it prevents guessing.

8.1.2 Research aim

The aim of this study was to investigate how individual student characteristics influence the learning paths they follow and the learning strategies they use when working with adaptive e-learning material.

By learning path we mean the way students go through the adaptive e-learning material. The path is characterized by the exercises that students do and the subsequent progress they make towards achieving the learning goal(s). The variables we measured to determine the learning path of students are: average step size chosen, average number of tries needed to complete an exercise, number of exercises completed and time needed to finish.

The learning strategies we determined are the students’ approach to exercises and their use of information sources, and the degree to which they regulate their learning by varying the step sizes.

The student characteristics we considered were selected based on the likelihood that they have an influence on learning paths and strategies. The characteristics we selected are: prior knowledge, study level, gender and intrinsic motivation. Students' prior knowledge is reported to have an influence on the way they self-regulate their learning [87] and on their approach to solving problems [80]. Students' study level is related to their prior knowledge. We expected to find, for example, that postgraduate students work more independently than undergraduates and look for information sources themselves. Gender was selected as a characteristic because it is reported to influence SRL [27] and the use of e-learning material [88], as mentioned above. The intrinsic motivation of students is reported to have a large influence on SRL [24]. Students with high intrinsic motivation are assumed to be more eager to understand the concepts taught rather than to just find the right answer.

The aim of the study was to find out whether there is a relation between student characteristics and the way students use adaptive e-learning material. The following research questions were formulated:

1. Does the adaptivity of the e-learning material work by letting students follow different learning paths?
2. What is the influence of students' prior knowledge, study level, gender and intrinsic motivation on their learning paths?
3. What is the influence of students' prior knowledge, study level, gender and intrinsic motivation on the learning strategies they use?

8.2 Methods

8.2.1 Research design

Students worked with adaptive e-learning material about the design of PCR primers, which is an important molecular biology technique required for gene technology. This module is called the PCR Tutor and is described in detail in Chapter 4. Students first attended a lecture on the applications of cloning techniques in molecular biology research. The following day, they worked with the PCR Tutor during a two-hour session. The instructor and several assistants were available to help them with the module. Student prior knowledge was measured by taking a pre-test. After the intervention, students' intrinsic motivation and demographic data were measured by a questionnaire. Learning paths and strategies were measured with self-report items in the questionnaire and obtained from traces from students' interactions with the learning material. The classroom procedure comprised three steps:

1. The participants took the pre-test individually. They were not allowed to use external information from textbooks, peers or the teacher.
2. The participants used the PCR Tutor by doing the exercises that were presented to them. They were allowed to use all the information sources they needed to do the exercises, such as textbooks, their peers and the teacher. The participants had to complete as many exercises as necessary to finish the task.
3. The participants filled out the questionnaire individually.

8.2.2 Participants

The participants were Wageningen University students who followed the Gene Technology course in May 2011. Of the 94 students, 86 completed the pre-test (step 1), all 94 finished the PCR Tutor (step 2) and 80 completed the questionnaire (step 3).

Of the 80 participants who completed the questionnaire, 55% were male and 45% were female. Most (76%) of the students were following a BSc programme and almost all the others (23%) an MSc programme. Although the students who completed the questionnaire represented 12 nationalities, the majority (75%) were Dutch. The ratio Dutch to international students differs between BSc and MSc. The majority of BSc students (90%), but a minority of the MSc students (22%) were Dutch. Most (88%) students were between 18 and 25 years old; the other (12%) students were older than 25 years.

8.2.3 Instruments

Various instruments were used to measure the variables. Those that describe the learning paths were measured by logging student interactions with the adaptive e-learning to yield traces. The variables to describing the strategies the students used were measured with self-reports (for approach to do the exercises, information sources used and chosen step size) and traces (for chosen step size in relation to the number of tries that were needed). The student characteristics were measured with a pre-test (for prior knowledge) and a questionnaire (for study level, gender and intrinsic motivation).

Traces

The system used in this study was adapted to enable tracing, as proposed by Winne [29]. The step sizes the students selected, the exercises provided by the system, the answers that students submitted to the exercises and the subsequent update of the learner model were logged. The average step size that students chose was calculated from the traces by:

$$AVGStep = \frac{(1 \cdot \Sigma S + 2 \cdot \Sigma M + 3 \cdot \Sigma B)}{\Sigma E}$$

where:

AVGStep	= Average step size
ΣS	= Number of small step sizes that were chosen
ΣM	= Number of medium step sizes that were chosen
ΣB	= Number of big step sizes that were chosen
ΣE	= Total number of exercises that were done = the number of step sizes that were chosen

The average number of tries was calculated by dividing the total number of answers that students submitted by the total number of exercises. The answers students submitted after finding the correct answer (some students do this in order to be able to read all the feedback) were not taken into account. The total number of exercises was deducted by counting the number of exercises that students made in order to finish the PCR Tutor. For example, a student who only chose big steps will have an average step size of 3. A student who only chose small steps will have an average step size of 1. A student who chose five small steps, two medium steps and one big step will have an average step size of 1.5.

The time students needed to finish the module was calculated by the period between the submission of the pre-test and the completion of the PCR Tutor.

We considered the variation in step sizes as the degree to which students regulate their learning. This was determined from the combined number of tries and chosen step size. These look like: B6 S1 M3. This code indicates that a student first chose the big step and needed six tries to complete the exercise. He or she then chose a small step and found the correct answer in one try. The student then chose a medium step and needed three tries to complete the exercise. Students were categorized into those who varied the step size and those who did not.

Pre-test

The students' prior knowledge was measured with a pre-test that consisted of one open question. This question was a complex exercise to design PCR primers, which was also the learning goal for the PCR Tutor (Figure 9 on page 55). The students' answers were scored using a scoring model that has previously been reported to be valid [89]. In short, the students could acquire one to six points, and those who obtained five or six points had achieved the learning goal (see 0).

Intrinsic motivation inventory

Information about the intrinsic motivation of the students was collected with a questionnaire. Learning behavior was measured in three subscales: appreciation of material, appreciation of computer-based education and usefulness of the subject. Items from the subscales are based on items from the Intrinsic Motivation Inventory [90] – which has also been described and used in an educational setting [91] – and extended with specific items for our study. Students participating in a pilot were interviewed to identify their interpretation of the items, since small changes in the wording of items can be very important [58]. Ambiguous items were revised. The reliability of the subscales, calculated as Cronbach's alpha, was measured (Table 13 on the next page). An alpha value above 0.7 is generally adopted as sufficient reliability, so all three scales are reliable. The corrected item-total correlations represent the correlations between each item and the total score from the scale. Items with a correlation above .3 correlate enough with the total score. All items correlated well, so deletion of items was not necessary.

Correlations between the three intrinsic motivation subscales were calculated. Spearman's correlations revealed that all scales correlated significantly at the .01 level (Table 14 on the next page). This indicates that the three intrinsic motivation subscales are related. The intrinsic motivation was thus calculated by averaging the score for the three subscales.

Table 13. The items and internal consistency of the three motivation scales from the questionnaire

Scale	Items	Corrected item-total correlation
Appreciation module	I enjoyed this module.	.72
	This module was boring	.53
	This module was challenging.	.65
	This module motivated me to think about the subject.	.60
	This module made learning about the subject more interesting.	.71
	I preferred this module on the subject to traditional learning module.	.33
	Reliability (Cronbach's α)	*.82*
Appreciation computer-based education	Using computer-based modules is a nicer way of studying the theory than completing assignments on paper.	.77
	I should like to do modules like this on a range of subjects and topics.	.72
	In general, I prefer using computer-based learning module to other types of learning material.	.72
	I like working with computers as part of my studies.	.59
	Reliability (Cronbach's α)	*.85*
Usefulness	I find the subject an interesting one.	.56
	I think having a good understanding of the subject is important for my studies.	.75
	Learning about the subject is useful.	.71
	Understanding the subject is important for my future career	.62
	Reliability (Cronbach's α)	*.82*

Table 14. Spearman's correlations between intrinsic motivation subscales

	Appreciation of material	Appreciation of computer-based education	Usefulness
Appreciation of material	-		
Appreciation of computer-based education	.631[a]	-	
Usefulness	.370[a]	.319[a]	-

[a] *Significant at .01 level*

Self-reports

Student self-reports about SRL strategies were used to support the results from the traced SRL. Self-reports were collected in three categories: approach to making exercises, step size choice and use of information sources (Table 7 on page 81).

Spearman's correlation coefficients, r_s, for the traced data and the self-report data were calculated to investigate the reliability of self-reporting by students. The time students reported to have spent on the PCR Tutor correlates very well with the logged time, $r_s = .59$, $p < .01$. The average step size correlates negatively with the self-report item 'I chose small steps', $r_s = -.70$, $p < .01$, and positively with 'I chose big steps', $r_s = .72$, $p < .01$. These strong correlations suggest a good reliability of student self-reports in this study. The self-report data were therefore used to measure the variables 'approach to doing exercises' and 'use of information sources'. These variables were not traced. The average step size that students chose is called 'step size choice' in further analysis.

8.2.4 Data analysis

We performed Mann-Whitney analyses and Spearman's correlations to study the influence of student characteristics on their learning paths and learning strategies. A level of .05 was adopted to test for significance. Mann-Whitney analyses were used for dichotomous data. This was the case with gender (man or woman), traced self-regulation (yes or no) and level of study (undergraduate or graduate). Effect sizes, r, for the results were calculated by:

$$r = \frac{Z}{\sqrt{N}}$$

Where:

z = the z-score from the Mann-Whitney analysis

N = the number of respondents

Spearman's correlation coefficients, r_s, were calculated for scaled variables, such as prior knowledge (scale 1-6) and intrinsic motivation (scale 1-5). Calculation of effect sizes is not needed for these correlations, since the correlation coefficients *are* effect sizes.

8.3 Results

8.3.1 Student characteristics

The results of the pre-test ranged from 1 to 5, with a mean (M) of 2.93 and a standard deviation (SD) of 1.28. These results indicate that the prior knowledge of the students varies. They also show that the students on average did not master the learning goal beforehand, since the average score is far below 5. Students achieve the learning goal with a score of 5 or 6. In this study, none of the students obtained a score of 6 for the pre-test. There were no significant differences between the pre-test scores of and female students, and between BSc and MSc students.

The intrinsic motivation of the students was measured by averaging three subscales. Students had a relatively high intrinsic motivation ($M = 3.74$). There were no significant differences between men and women in their intrinsic motivation, $U = 682.50$, $p > 0.05$. The intrinsic motivation of students in the MSc phase (*Median* (*Mdn)* = 4.08) was higher than that of students in the BSc phase ($Mdn = 3.71$), $U = 306.00$, $p < 0.05$, $r = -.032$. No relation was found between students' prior knowledge and their intrinsic motivation, $r = .07$, $p > .05$

8.3.2 Strategies

The self-reported learning strategies are presented in Table 15. Generally, students reported reading the text of the exercise carefully before selecting the best answer ($M = 4.36$). Guessing the answer without reading the text was rarely done ($M = 1.06$). The feedback on incorrect answers is often read ($M = 4.63$), the feedback on correct answers is moderately often read ($M = 3.50$). The other information sources, including the online library, are used less often (3 questions, mean range 1.54-2.26).

The self-reports show that 23 students did not choose the step size consciously, while 55 did.

8.3.3 Learning paths

The learning path a student follows is determined by average step size chosen, average number of tries, total number of exercises and time needed to finish. The average step size per student varied within the range of 1 to 3 ($M = 2.04$, $SD = .59$). The average number of tries per student ranged from 1.0 to 3.5 ($M = 2.0$, $SD = .51$). The time students spent on the PCR Tutor ranged from 10 to 156 minutes ($M = 37$, $SD = 22$). The number of exercises students needed to finish the module ranged from 1 to 29 ($M = 11.7$, $SD = 7.45$).

We illustrate the variation in learning path followed by presenting the number of credit points that fourteen randomly chosen students earned as a function of the number of exercises they completed (Figure 13 on the next page). The indicated learning paths are determined by the chosen step sizes, the exercises that the system selected for the student to do and the number of tries a student needed to complete the exercise. Time is not taken into account in this figure. Note that students sometimes loose credit points (for one case indicated by arrow).

Table 15. Descriptive statistics for self-report items on learning strategies on a 5-point scale (1=never, 2=seldom, 3=sometimes, 4=often, 5=always)

	n	Mean	(SD)
Approach to doing exercises			
I studied relevant theory on the exercise before working on it. I then selected the best answer.	79	2.56	(1.22)
I read the exercise carefully and selected the best answer.	80	4.36	(.72)
I read the exercise and took a guess at first. Then I read the feedback and tried to select the right answer.	79	2.13	(1.03)
I didn't read the exercise and guessed the answer.	78	1.06	(.30)
I discussed with my fellow students what the best answer would be, and then chose that answer.	79	1.77	(1.09)
I asked the teacher to explain the exercise before submitting an answer.	79	1.24	(.60)
Information sources			
I read the feedback on incorrect answers.	80	4.63	(.75)
I read the feedback on correct answers.	80	3.50	(1.36)
I used the information in the online library.	80	2.26	(1.26)
I used the information sources when the feedback directed me there.	80	2.11	(1.27)
I used the Internet to find additional information.	80	1.54	(1.03)

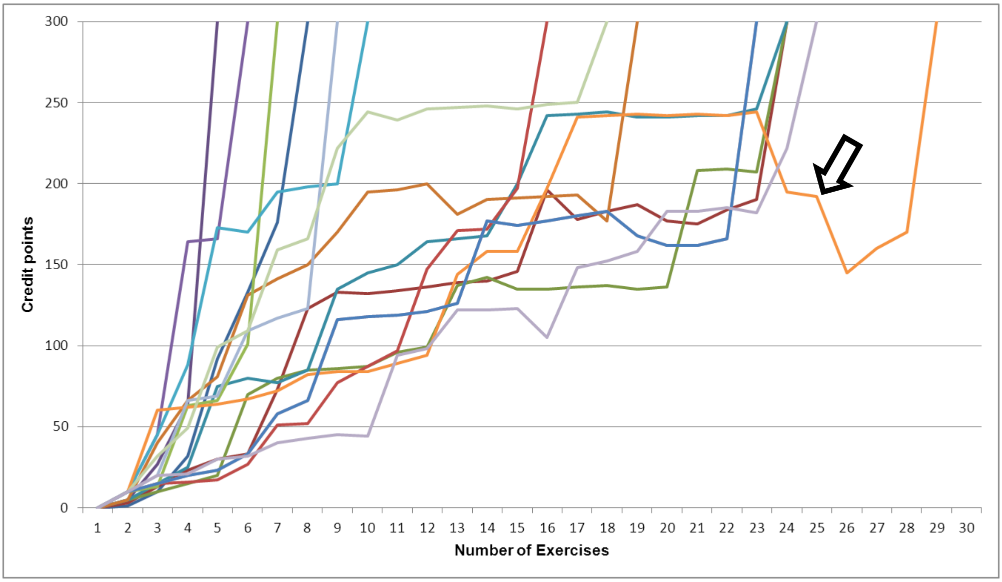

Figure 13. The learning paths of 14 randomly chosen students are shown. The number of credit points gained is plotted against the number of exercises completed. Both parameters were collected by traces. The threshold level to finish the module is 300 credit points.

Correlations between the four variables that were measured to determine the learning paths were calculated (Table 16). The logged step size choice correlates with the number of exercises that were needed but not with the number of tries. The step size choice correlates negatively with the time spent on the PCR Tutor, so students who chose bigger steps needed less time.

Table 16. Spearman correlations of the variables that determine the learning path

	Number of exercises	Number of tries	Step size choice	Time spent
Number of exercises	-			
Number of tries	-.06	-		
Step size choice	-.80[a]	.13	-	
Time spent	-.41[a]	.08	-.41[a]	-

[a] *Significant at .01 level*

8.3.4 Student characteristics and learning paths

No difference was found between men and women in their learning path variables. BSc students needed on average fewer exercises to finish (*Mdn* = 10.5, *M* = 11.2) than MSc students (*Mdn* = 16.5, *M* = 15.7), *U* = 333.5, $p < 0.05$, *r* = -.28. The average number of tries per exercise did not differ for BSc and MSc students. The average step size did differ, however: BSc students chose bigger steps (*Mdn* = 2.09, *M* = 2.14) than MSc students (*Mdn* = 1.74, *M* = 1.61), *U* = 270.0, $p < 0.05$, *r* = -.36. BSc students (*Mdn* = 28.0, *M* = 29.6) needed less time to finish than MSc students (*Mdn* = 54.0, *M* = 60.4), *U* = 78.5, $p < 0.05$, *r* = -.53. These effects are all medium to large with an effect size (*r*) around 0.30-0.50.

Spearman's correlation coefficients, r_s, of prior knowledge and intrinsic motivation with the learning paths are shown in Table 17. The intrinsic motivation of students correlates negatively with the average step size they chose, meaning that students who have a higher level of intrinsic motivation chose smaller step sizes. The intrinsic motivation also correlates negatively with the number of tries that students needed, but we did not find a relation between prior knowledge and the number of tries that were needed. Intrinsic motivation correlates with the time students spent on the PCR Tutor, meaning that students with higher motivation needed more time.

Table 17. Spearman correlations of student characteristics and learning path variables

	Prior knowledge	Intrinsic motivation
Number of exercises	- .14	.16
Number of tries	- .14	- .26[a]
Step size choice	.09	- .25[a]
Time spent	- .16	.26[a]

[a] *Significant at .05 level*

8.3.5 Student characteristics and learning strategies

The results of the self-reported learning strategies are presented in Table 15 on page 107. There are no differences between men and women in the self-reported strategies. MSc students (*Mdn* = 4, *M* = 3.24) more often studied relevant theory before doing an exercise than BSc students (*Mdn* = 2, *M* = 2.38), *U* = 315.50, $p < 0.05$, *r* = -.29. MSc students (*Mdn* = 3, *M* = 2.71) also more often guessed at first and then used the feedback to find the correct answer than BSc students (*Mdn* = 2, *M* = 1.97),

$U = 345.50$, $p < 0.05$, $r = -0.25$. MSc students ($Mdn = 1$, $M = 1.59$) more often asked the teacher to explain the exercise than BSc students ($Mdn = 1$, $M = 1.15$), $U = 383.50$, $p < 0.05$, $r = -0.30$. These effects are all small to medium with an effect size (r) of between 0.25 and 0.30.

The self-reported learning strategies were correlated with the prior knowledge and intrinsic motivation of students (Table 18). Students who had a higher level of prior knowledge less often discussed with their fellow students to find the correct answer and chose the step size more consciously. Students with higher intrinsic also chose the step size more consciously and used the information sources more. The correlations that were found are not very strong, with an effect size around 0.3.

Table 18 Spearman correlation coefficients for pre-test and intrinsic motivation and self-report items on three learning strategies.

	Prior knowledge	Intrinsic motivation
Approach to doing exercises		
I studied the relevant theory before doing the exercise. I then selected the best answer.	.00	.14
I read the exercise carefully and selected the best answer.	.13	-.22
I read the exercise and took a guess at first. Then I read the feedback and tried to select the right answer.	-.16	-.07
I didn't read the exercise and guessed the answer.	.23	-.13
I discussed with my fellow students what the best answer would be, and then chose that answer.	-.28[b]	-.09
I asked the teacher to explain the exercise before submitting an answer.	-.08	.13
Regulation of step sizes		
I consciously chose the step size.	.24[b]	.26[b]
Information sources		
I read the feedback on incorrect answers.	.00	.31[a]
I read the feedback on correct answers.	-.04	.33[a]
I used the information in the online library.	-.21	.20
I used the information sources when the feedback directed me there.	-.11	.30[a]
I used the Internet to find additional information	-.18	-.03

[a] *Significant at .01 level*
[b] *Significant at .05 level*

The traces provide information about the degree to which students changed their step size selection when working on the PCR Tutor. Thirty-one students did not change the step size they selected, while 46 students did change it. Men and women did not differ in their variation of step sizes, nor did BSc and MSc students. There is no relation between the intrinsic motivation of students and their step size variation, $U = 692.5$, $p > .05$. Students who did not vary the step sizes had a higher level of prior knowledge (*Mdn* = 3, *M* = 3.4) than students who varied the step sizes (*Mdn* = 3, *M* = 2.6), $U = 561.0$, $p < .05$, $r = -.30$. Of the 31 students who did not change their step sizes, most of them (22) made a conscious choice not to change them. Of the 46 students who varied their step sizes, 32 did so consciously.

8.4 Discussion and conclusions

The aim of this study was to investigate whether students follow different learning paths when using adaptive e-learning, and whether learning paths and strategies relate to student characteristics. The results show that students do indeed follow individual learning paths. They need a varying number of exercises to finish the task; the number is determined mainly by the step size they select to master the set learning objectives. As answer to the first research question, we therefore state that the adaptivity of the system works and that the option to choose step sizes is an essential factor in the system's adaptivity. In addition, students who chose bigger steps needed less time, indicating that students were well able to predict their own capacities.

The findings of this study indicate that some student characteristics are related to their learning paths. Gender and prior knowledge did not have an effect. BSc students needed less exercises and less time to finish than MSc students. This difference relates to the observation that BSc students chose bigger steps than MSc students. These findings are likely caused by the different compositions of the BSc and MSc student groups. Most of the BSc students were Dutch (90%) while the MSc students represented a large variety of nationalities with only 22% Dutch. This means that the nationality of students confounds with the study level and that more research is needed to attribute the reported differences between BSc and MSc students to the correct characteristics. Intrinsic motivation unexpectedly had a bigger influence on the learning path than students' prior knowledge. This can be explained by the desire of highly intrinsically motivated students to really understand the subject: they chose small steps in order to get more practice. These highly motivated students then need more time but also fewer tries to complete the exercises with the small steps, which is expected because they do not have less prior knowledge. Thus, the answer to the second research question is that intrinsic motivation has an influence on students' learning paths, and this is caused by the average step sizes they choose.

We also investigated the relation between student characteristics and the strategies they used when working with the adaptive e-learning material. The gender of students did not affect their learning strategies. Students who had a higher level of prior knowledge less often discussed with their fellow students to find the correct answer and chose the step size more consciously. Compared to BSc students, MSc students more often studied relevant theory before doing an exercise, guessed at first and then used the feedback to find the correct answer, and asked the teacher to explain the exercise. Students with higher intrinsic chose the step size more consciously and used the information sources more. The effect size of these relations was not very high. Thus, the answer to the third research question is that although intrinsic motivation, study level and prior knowledge do relate to the strategies that students adopt, these relations are not very strong.

This study presents insights into the ways students use adaptive e-learning. However, some limitations should be mentioned. An important one concerns the content of the PCR Tutor. Students could achieve the learning objective by completing only one exercise or a small number of them. The students who finished with very few exercises found it hard to complete the questionnaire, since they could not use many different learning strategies. In this study, 13 students needed three exercises or less to finish. As mentioned in the introduction, cultural background may have an influence on the learning strategies that students adopt. The students in this study differed in their cultural backgrounds: they came from the Netherlands, China, Ecuador, Ethiopia, Germany, Greece, Indonesia, Iran, Italy, Malaysia, Nepal and Vietnam. The variety in cultures was so great and student numbers per culture so small that it was not possible to compare groups with similar characteristics. The cultural background was therefore not taken into account in this study.

This study contributes to the educational research on SRL with CBLEs. We support the importance of using traces with CBLEs to gain more information about student SRL. Because adaptive e-learning gives the student some control, self-regulated learning strategies can well be studied. This study explored the possible influence of student characteristics on their learning paths and learning strategies, and touched upon some strategies that can be seen as self-regulated learning. For further research, we suggest using existing models [92] to describe SRL in order to obtain better identification of the self-regulated learning strategies. The adaptive e-learning system that was used to create the PCR Tutor has also been used to create learning material for other courses. Thus, some students may have already been familiar with this type of adaptive e-learning material. It has been reported that novices interact differently with e-learning material than more experienced students [24]. It is therefore interesting to measure the experience students already have with the specific learning environment and relate this characteristic to the learning path followed and strategies used.

This study provides empirical data to support the hypothesis that adaptive e-learning material provides personalized instruction to heterogeneous groups of students. We therefore recommend teachers to consider using adaptive e-learning material when faced with a heterogeneous student group, especially if it is a mixed group of BSc and international MSc students.

Part IV General Discussion

This part summarizes the findings from the research described in Chapters 4 to 8. In Chapter 9, the results from the previous chapters are combined to answer and discuss the answers to the three research questions of this thesis. Chapter 9 also summarizes the overall findings from the research and discusses some limitations of the study. Chapter 10 reflects on the educational impact of the outcomes of this study. Recommendations for further research and adaptations to the adaptive e-learning system Proteus are given.

Chapter 9
Reflections on the study

The purpose of this study was to investigate if and how adaptive e-learning created with Proteus delivers effective personalized instruction to individual students. Several adaptive e-learning modules have been developed within the framework of this study. In addition, a method was developed to calibrate the level of exercises based on the classification of (sub) learning goals. The adaptive e-learning system was also adapted to enable the logging of traces needed to carry out the research. In Chapter 1 three research questions were formulated and in this chapter we combine the results from the preceding chapters to answer them. In addition, we reflect on the methods that were used to answer the research questions.

9.1 Personalizing education with Proteus

Research question 1 is: *In what way does adaptive e-learning material created with Proteus provide personalized instruction and how do students use and appreciate these adaptive features*?

To answer the research question, we have studied three adaptive modules to investigate which features of adaptive e-learning students use to personalize their learning. The modules differ in the domain knowledge they cover, *i.e.* cell growth kinetics (Chapter 6), enzyme kinetics (Chapter 7) and PCR primer design (Chapters 4 and 8). All modules were created with the same system: Proteus. Proteus offers three ways to personalize instruction: Adaptation of the number of exercises in response to (1) the step sizes students select and (2) the number of incorrect answers given, and (3) the presentation of tailored feedback after an answer has been submitted to an exercise.

The first study investigated the variation in number of exercises without looking at the individual contributions from step size selection and incorrect answers (Chapter 6). The results from this study show that the number of exercises that students needed to finish the module varied. We continued the research by measuring the individual contributions of selected step size and number of incorrect answers given.

To be able to measure the variation in step size choice and the number of incorrect answers, items were added to the questionnaire that was given after the module had been finished. Results from the use of the CGKT indicate that students vary their step sizes (Chapter 6), but we did not acquire information about the degree of variation and about the specific steps that were selected. The step sizes that students selected were therefore logged with the EKT (Chapter 7) and PCR Tutor (Chapter 8). The results from these studies support the conclusion that there is variation between students in the step sizes they chose. The questionnaire showed that students were relatively positive about the ability to choose steps sizes (Chapters 7 and 8). We therefore conclude that students use and appreciate the adaptive feature to choose step sizes.

Together with the step size choice, the number of incorrect answers that students give determines the number of exercises that are needed to finish the adaptive e-learning modules studied in this thesis. We investigated the logged answers that were submitted by students using the PCR Tutor (Chapter 8). The results show that the average number of incorrect answers indeed varies among the students, indicating that the variation of exercises contributes to personalized instruction.

The third way that our adaptive e-learning uses to offer personalized learning is tailored feedback. We collected data about the use and appreciation of the feedback by students who used the EKT or the PCR Tutor with a questionnaire. Our results show that students read the feedback that is provided by the system. Feedback to incorrect answers is read more often than feedback to correct answers. Students were relatively positive about the usefulness of the feedback (Chapter 7 and 8).

To conclude, students use all available adaptive features to personalize learning and do appreciate it. Students varied in the step sizes they chose and the number of incorrect answers they gave. They also read and appreciate the feedback that was provided.

9.2 Effectiveness

Research question 2 is: *How effective is the adaptive e-learning material created with Proteus in generating a basic knowledge level within a heterogeneous student group?*

We have measured the learning effectiveness of the adaptive e-learning by assessing the students with end-of-course exams and pre- and post-tests. End-of-course exams are similar to post-tests, but the timespan between the intervention and the test is longer: 3-4 weeks compared to post-tests which were taken directly after a student finished the module. For the CGKT, end-of-course exam scores from three cohorts of heterogeneous student groups consisting of regular and exchange students were measured. One cohort did not use the module and two cohorts did use the module (Chapter 6). The scores for module-related questions from the exam were normalised against the total score for the total exam. The exam scores were not very high for both student groups. The differences between the exam scores of regular and exchange students however decreased severely after introduction of the CGKT. The findings thus show that the CGKT was successful in providing both student groups with a similar knowledge level, which enhances teaching. For the PCR Tutor, students' knowledge gain was measured with pre- and post-tests (Chapter 4). Most of the students had obtained the required level as set by the developer in this study. The PCR Tutor thus was effective in obtaining the required basic knowledge level.

In short, the use of adaptive e-learning material is effective in providing students in a heterogeneous group with a shared basic knowledge level.

9.3 The relation between student background and personalization

Research question 3 is: *Which student characteristics influence their learning paths and strategies when using adaptive e-learning material created with Proteus?*

We answered this research question by collecting data about the students and about the ways they used adaptive e-learning material. The data that we collected about the students were prior knowledge, study level, gender, intrinsic motivation, and nationality. The data that we collected about the way students used adaptive e-learning material were the learning paths they followed, the learning strategies they used when making the exercises and the degree to which they self-regulated their learning. The learning path was defined by: (1) the step sizes that students selected, (2) the number of tries they needed to answer the subsequent exercise correctly, (3) the number of credit points that students obtained after finishing the exercise and (4) the variation in step size selection with regard to the number of tries students needed. The learning strategies that students used consisted of the approach they take to make an exercise and the information sources they used. The degree to which students self-regulated their learning concerns the information sources they used and the extent to which they varied their chosen step sizes.

We studied the possible relations between student characteristics and the way they used adaptive e-learning material with the PCR Tutor (Chapter 8). The results indicate that gender does not have an effect on students' learning paths and strategies, which is contrary to findings from literature [27]. Unexpectedly, we did not find a relation between the prior knowledge of students and the average number of incorrect answers they gave. The BSc students that participated are almost all Dutch. The MSc students were from twelve different countries. Compared to BSc students, MSc students had a higher intrinsic motivation and more often studied relevant theory before making an exercise, guessed at first and then used the feedback to find the correct answer and asked the teacher to explain the exercise. Students with more prior knowledge less often discussed with their fellow students to find the correct answer and chose the step size more consciously. Students with higher intrinsic motivation also chose the step size more consciously and made more use of the information sources more. It was not possible to measure the influence of nationality because of the small number of students per nationality so more research is needed to study the effect of study level and the effect of nationality separately.

Summarizing, the student characteristics that were found to have an influence are: prior knowledge, study level, and intrinsic motivation. Gender did not have an effect.

9.4 Reflections on research methods and conditions

The methods that were used to answer the research questions concern quantitative analysis of qualitative data that was collected in real classroom situations. Data collection was conducted with questionnaires, tests and traced interactions with the adaptive e-learning system. We measured variables with scales by using Likert-scale items when possible. The responses to these questionnaire items were analysed by non-parametric Mann Whitney tests to identify differences between groups. We have measured the reliability and validity of the questionnaire items. Where possible, self-reported items were compared to factual data obtained from the traces. This comparison showed a good reliability of the self-report items. The items that were measured with scales showed a good internal consistency. The validity of the questionnaire items was warranted by interviewing a test panel of respondents about their interpretation of the items and revising ambiguous items.

In this study, end-of-course exam scores (CGKT) and pre- and post-test scores (PCR Tutor) were analysed to assess students. The use of end-of-course exams to analyse students' learning outcome has severe limitations. The questions in the end-of-course exams were not formulated by the researcher and the validity of these questions was not measured. Also, the prior knowledge of students was not measured, so the knowledge gain could not be determined. We corrected for this by comparing students' scores for the adaptive e-learning module-related question with their total exam score. As described above, end-of-course exams are given some weeks after the intervention. Learning outcomes that are measured with end-of-course exams can thus not unambiguously be assigned to the intervention alone. Pre- and post-tests do not have these limitations, but taking a pre-test can influence results since students are known to learn from such tasks [94].

Some remarks should also be made about the adaptive e-learning material that was investigated in this study. The PCR Tutor (Chapter 4) had a limited scope. The module only covers a small number of learning goals, i.e. only one main learning goal and eight sub-learning goals. Students with the required prior knowledge can therefore finish the module by making one exercise. Although this is not a problem for the functionality of the PCR Tutor in teaching the required concepts, it was a drawback for the research data analyses. It was difficult to characterize and further analyse the learning paths of these students. Another limitation was that the assignment of credit points to the exercises in the CGKT (Chapter 6) and the EKT (Chapter 7) was not done using the systematic arrangement described in Chapter 4. Students complained that the relation between the choses step size and the complexity of the exercises they received was unclear.

The studies described in the chapters 4, 6, 7 and 8 were carried out with different versions of Proteus, different modules, different teachers and at different universities (see Table 1 on page 19). In addition, the student populations that were studied varied in size, response rates and composition. These differences reflect a broad applicability of the material, but make it difficult to compare results between studies.

9.5 Concluding remarks

With the work described in this thesis we want to provide teachers with practical guidelines about when and how to use adaptive e-learning material to educate their heterogeneous student groups. Strictly spoken every student group is heterogeneous since it consists of individuals with their own learning preferences, aptitudes and prior knowledge. Since every student group is heterogeneous, we argue that personalized education using adaptive e-learning material is always beneficial. But the development of adaptive e-learning material is costly and time-consuming. We evaluated adaptive e-learning material that has been developed and used to educate heterogeneous groups at Wageningen University in biotechnology. Our findings show that the modules are effective to teach heterogeneous student groups. We also showed that the adaptive features of the modules are indeed exploited. We found that individual student characteristics such as prior knowledge, study level and motivation have an influence on their use of the adaptive e-learning material. The next chapter describes the possibilities for further research and recommendation for adaptations of the investigated adaptive e-learning system Proteus.

Chapter 10
Lessons learned and recommendations

The e-learning material used in this thesis was created using Proteus. The research questions focused on the effectiveness of using Proteus, the ways in which the learning material created with Proteus personalizes education, and the relation between student characteristics and their use of the learning material. In this chapter we will elaborate on the findings from the research described in this thesis to give recommendations for further research. The topics that will be addressed are: feedback, learning processes, teaching heterogeneous student groups, features of Proteus and distance learning. The first two topics contribute to research in educational science and the other three topics aim to support teachers with the design, use and implementation of adaptive e-learning material. The chapter concludes with an outlook of the impact of this study.

10.1 Tailored feedback

One of the adaptive features of Proteus is the presentation of tailored feedback to individual students. Our results show that students read the feedback to both correct and incorrect answers they gave. We did not discriminate between the different types of feedback (specific feedback and general hints) and also did not investigate *how* students used the feedback to find the correct answer. Our findings show that students were only moderately positive about the helpfulness of the feedback. It is useful to investigate why students do not consider all feedback to be clear or helpful. Some possible approaches are indicated below.

To further investigate the use of different types of feedback, different approaches can be taken. Proteus can be modified to also log the feedback that is delivered. These feedback traces can then be analysed for satisfied and unsatisfied students to reveal differences. More information about the opinion of students of the usefulness of feedback can be collected by letting students rate the feedback they received. Additionally, we could use observations or think-aloud methods to get more insight into the effectiveness of specific types of feedback.

Studying the use of feedback by students, we should take into account students' expectations. Students are reported to look for executive help or instrumental help [93]. Executive help is help in finding the correct answer. Instrumental help provides information to understand the concepts that are being taught. In our learning material, we give instrumental help. Students who wish to receive executive help are thus not served. It is therefore recommended to investigate the effects of feedback types to different groups of students and extend the adaptive system with opportunities to include executive as well as instrumental feedback.

It is known from literature that feedback is most powerful when it addresses faulty understanding, not a total lack of knowledge about the subject [1]. To provide students with the information they need to make an exercise, hyperlinks to relevant documentation can be made available in the question. Another possibility is the addition of a hint button to the exercises: students will be able to click the button and receive additional instructions at the cost of credit points. Students are challenged to reflect on their learning and this will stimulate their self-regulation (FR).

10.2 Learning processes

We studied the relation between student characteristics and the learning paths and learning strategies of students when using adaptive e-learning material (Research question 3). We briefly looked at the self-regulated learning strategies that students adopt. We showed that is it possible to use traces generated by the education system and student self-reports to get more insight into self-regulated learning by students. Using adaptive e-learning material to study self-regulated learning by students is a promising method [29]. The traces provide objective information that is obtained in a non-invasive manner through an authentic learning activity. The use of adaptive e-learning material ensures that the student has some control and is therefore able to self-regulate. This makes adaptive e-learning an exquisite tool to study self-regulated learning.

Computer-based learning environments like the one investigated in this thesis provide many more possibilities to perform research. As stated previously, research questions on students' conceptual knowledge can also be studied with traces. An analysis of the answers students submit to exercises can provide valuable information about their understanding of specific topics. The answers that students submit to exercises in the adaptive e-learning modules that are investigated in this thesis, were all logged. It is therefore possible to perform qualitative as well as quantitative analyses on these answers to identify common misconceptions. The analyses of these answers will provide useful information about the differences between students in the alternative conceptions they have. These findings can then be used to adjust the answer options and feedback of exercises.

10.3 Teaching heterogeneous student groups

Chapter 1 of this thesis describes the challenge of educating heterogeneous groups of students. Several solutions can be considered when the variety of learning styles hampers teaching. A possible solution is described in this thesis and concerns the personalization of education using adaptive e-learning. The current developments of internationalizing (higher) education lead to an expected increase in the use of personalized education. We therefore believe that continued research in the field of personalized education is of increasing relevance.

10.4 The adaptive e-learning system Proteus

This section describes some shortcomings and possible improvements of the adaptive e-learning system Proteus. We describe our experiences and those of the many students who used the system at different institutions in the Netherlands and abroad and over a period of seven years.

10.4.1 The relation between chosen step size and complexity of the exercise

Proteus is designed to be a teacher-friendly tool to create adaptive e-learning material [47]. The amount of data that a teacher has to assign to an individual exercise is indeed small, making it easy work for him. But the interpretation of the start and end levels of the exercises is not trivial and not very easy to understand (Chapter 4). Only the end-levels of exercises are coupled to the step size. Students often intuitively relate the step size to complexity. Since only the end-levels of exercises (and not the difference between start- and end-levels) of an exercise are taken into account when associating an exercise to a chosen step size, is unclear for many students who use the material.

In this study, an alternative method to design adaptive e-learning material was developed to assign complexities to exercises that are more firmly coupled to chosen step sizes. For the development of the PCR Tutor, our method used the Taxonomy of Educational Objectives and that divided objectives into sub-learning objectives (Chapter 4). This method was successfully used to categorize exercises according to complexity and to attribute credit points to exercises based on this categorization. This way, the chosen step size by students relates to the complexity of the selected exercise.

10.4.2 Limitations to the adaptivity

Proteus is designed to contain a pool of exercises that are presented in an adaptive way to students, taking into account the individual student level and step size preference. Only a few parameters have to be set to make adaptive e-learning material with Proteus. This small amount of information makes the system relatively easy to use compared to systems that require more information; however, it also restricts its adaptability. Three improvements are suggested below.

The first improvement concerns the recognition of mistakes made by the student. It is possible for a student to keep making the same mistake or type of mistake without the system recognizing this. An improvement would be to have a parallel scoring next to the overall scoring that the system logs to monitor the progress of students. This parallel scoring can log the specific mistakes students make. If a student repeatedly makes the same type of mistake, the feedback can then be adapted and the students can be directed to relevant information.

The second improvement concerns the choice of step sizes. A student chooses a step size after each exercise. The system does not automatically switch to a bigger step size after many correct answers. This enhances self-regulated learning of the student, since he or she can always choose the step size. However, our findings show that students do not often change the step size they choose. An improvement is therefore to automate the selection of step sizes. A student would, for instance, choose the step size at the beginning of the material, but if he or she gave many correct answers, the system could switch to bigger steps, and if the student gave many incorrect answers, the system could switch to smaller steps. This approach is widely used in computerized adaptive testing [45].

The third improvement concerns the step size selection at the end of a module. At that stage, selection of the step size has less effect, because few exercises are left. Thus, students can get exactly the same exercise when choosing a big or small step size. In other words, the system feigns self-control of the student over their learning, while this is not the case. Students report that they consider this unclear ("*The difference [between step sizes] was not very clear, because some exercises were sometimes classified as medium step and sometimes as big step.*"). A solution is to increase the number of exercises, so it is much larger than the students have to make.

10.4.3 Limitation to the scoring mechanism

The number of credit points that a student receives after completing an exercise depends on two parameters: the difference between the student level and the end level of the exercise, and the number of tries that the student needed. The exercises that are part of the material can be of different types (see Chapter 3). Some exercise types have a limited number of possible answers (e.g. multiple choice questions), while others have many possible combinations (e.g. open-ended questions and drag and drop exercises). The system does not take this difference into account when assigning credit points, because it is currently not possible to assign a different score to answer alternatives. Some answers are more 'wrong' than others, but the system cannot differentiate between these answers. This makes the system less adaptive. A solution is to make it possible to assign a different scoring mechanism to different exercise types and different scores to individual answer alternatives.

10.4.4 Randomization of topics

Students can choose the step size for the next exercise. However, Proteus selects the topic for the subsequent exercise in a random way. Students thus do not know which topic the exercise will be about. When varying topics are covered in one module, this makes it impossible for them to choose a step size. Although randomization makes it difficult for students to choose a step size, it did not affect the performance of students at post-tests [94]. A way to get around this problem is to select topics based on their coherence. Topics that differ a lot can better be offered in separate Proteus modules. Another solution is to inform the student about the topic of the next exercise before he or she chooses the step size.

10.5 Distance learning

In addition to the increased student mobility, another important development in higher education is the advent of distance learning, which is one of the major future plans of Wageningen University. Distance learning allows students to follow study programmes at home. It therefore opens up opportunities to those who, for example, cannot travel to university because of their financial situation. In addition, distance learning can be used to train personnel of companies and research institutions. Education does not stop after graduation and training keeps personnel updated about recent developments in the field. Such 'lifelong learning' is enhanced by the use of distance education. The expected audience for distance learning is thus just as heterogeneous as (if not more heterogeneous than) the current MSc student population. For this reason, adaptive e-learning can play an important role in the development of distance education courses.

10.6 Outlook

The research described in this thesis provides insight into the effectiveness and applicability of adaptive e-learning material to educate heterogeneous student groups in higher education. We provided empirical research about how individual differences contribute to the differences in studying in computer-based learning environments. Our findings can be applied and extended to varying scientific disciplines. Information about the effectiveness of adaptive e-learning material aids teachers and school management in their selection for learning material. In addition, the use of adaptive e-learning material by students can be studied to yield information about the effectiveness of computer-based and adaptive feedback, about self-regulated learning of students, and about discipline specific issues.

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Summary

The increased heterogeneity of student groups participating in study programs at universities calls for the personalization of biotechnology education. This thesis evaluates a possible approach to personalize education by using adaptive e-learning material. The adaptive e-learning material developed in this study was evaluated with two aims in mind: to yield practical solutions for teachers who have to educate heterogeneous groups of students and to contribute to the scientific knowledge on self-regulated learning. Three central research questions are formulated in **Chapter 1**:

1. In what way does adaptive e-learning material created with Proteus provide personalized instruction and how do students use and appreciate these adaptive features?
2. How effective is the adaptive e-learning material created with Proteus in generating a basic knowledge level within a heterogeneous student group?
3. Which student characteristics influence their learning paths and strategies when using adaptive e-learning material created with Proteus?

Each chapter in this thesis contributes to one or more of these central research questions.

Chapter 2 provides background information on prior research about adaptive e-learning. Adaptive e-learning material is created with adaptive e-learning systems. Adaptive e-learning systems consist of multiple components that together enable tailored instruction to the individual students' needs. These components are: the content model, the learner model, the instructional model and the adaptive engine. The adaptive system that is investigated in this study allows for regulation of learning by students, next to the regulation by the system, and provides tailored feedback. Being able to regulate one's own learning is viewed by educational psychologists and policy makers alike as the key to successful learning in school and beyond. Using adaptive e-learning material to study the degree of self-regulated learning is a promising tool because data can be obtained in a non-invasive way while students work with the adaptive e-learning material. Good feedback strengthens students' capacity to self-regulate their own performance and is therefore an important aspect to take into account when investigating self-

regulated learning. It is thus important to design good feedback when developing adaptive e-learning material.

Chapter 3 discusses the adaptive e-learning system Proteus that is used to create the adaptive e-learning material that is evaluated in this thesis. Proteus adapts the amount of training and the content of feedback that students receive. The adaptation of the amount of training and the feedback takes place during students' interaction with the e-learning material. The amount of training is adapted to fulfill the needs of students with little prior knowledge, but without giving too much repetition to students with more prior knowledge. The content of the feedback targets specific mistakes that students make. The system varies the number of exercises according to the answers students submit to exercises related to the same learning objective. In addition, to establish the second mode of personalization, the system lets students choose the next exercise according to three levels of complexity (step size). Thus, three parameters contribute to the adaptive features of the system. Two are system-driven, namely (1) the number of exercises that have to be made and (2) the presentation of feedback and hints. The other is student-driven, namely the choice of step size for the next exercise.

Chapter 4 describes a new method that is used to create adaptive e-learning material with Proteus. With this method there is a clear relation between the complexity of an exercise and the chosen step size by students. In this chapter, we describe a way to determine the complexity of the exercises in a more objective way. Rather than basing the complexity on the teacher's experience, we applied three levels of the Educational Taxonomy of Learning Objectives to design learning goals with increasing complexity level, namely remember, understand and apply. We then developed exercises for each of the learning goals. The assignment of exercises to the learning goals was affirmed by a second scientist. The resulting adaptive e-learning material created with the new method was tested for learning effectiveness by conducting a pre- and a post-test. The material proved to be effective in teaching the basic of PCR primer design. The adaptive e-learning material thus created was used in further studies as described in **Chapter 8**.

Chapter 5 describes the evaluation instrument that was developed to measure the variables needed to answer the three research questions. The tools that were developed are a pre- and post-test, a questionnaire with attitude scales and self-report items and traces. Traces are logged interactions of students with the adaptive e-learning material. The step sizes that students select, the exercise they get, the answers students enter and the credit points they receive are all logged. The reliability and validity of the attitude scales of the questionnaire were measured and proved to be sufficient. The validity of the self-report items was guaranteed by interviews with participants. The reliability of the pre- and post-test was measured by having a second rater score students' answers. This measured reliability was high. Evaluations were carried out with increasingly mature versions of the evaluation instrument.

Chapter 6 evaluated the use of adaptive e-learning material about cell growth kinetics: the Cell Growth Kinetics Tutor (CGKT). Aim of this adaptive e-learning material is to provide students with the basic knowledge level on cell growth kinetics they need to comprehend the content knowledge of the subsequent lectures and pass the exam. Data of three student cohorts were investigated. The student groups consisted of students who had received their prior education in the Netherlands (regular students) and those who had not (exchange students). Exam scores, questionnaires, and traces of the students were analysed to discover whether the adaptive e–learning material had the intended effect. The results indicate that students did indeed follow different learning paths. Also, the difference in exam scores between the regular and exchange students that was present before the introduction of the material was found to have decreased afterwards. Students on average scored better after introduction of the CGKT. In general, students appreciated the use of the material regardless of their prior education. We therefore conclude that the use of adaptive e-learning material is a possible way to tackle the problem of differences in prior education of students entering a course.

Chapter 7 evaluates the developed adaptive e-learning material about enzyme kinetics: the Enzyme Kinetics Tutor (EKT). In this study, we investigated which adaptive features of the EKT were used by a group of 48 life science undergraduates. We also measured students' appreciation of the EKT. Students were positive about the use of the EKT and appreciate the personalization features. Our findings show that the EKT offers personalized instruction by varying the number and level of the exercises and providing tailored feedback.

In **Chapter 8**, we investigated the influence of individual student characteristics on their use of adaptive e-learning material. We determined characteristics in a heterogeneous student group by collecting demographic data and measuring motivation and prior knowledge. We also measured the learning paths students followed and learning strategies they used when working with the PCR Tutor. We then combined these data to study whether student characteristics relate to the learning paths and strategies they used. Our findings show that gender did not have an effect, but students with different prior knowledge, different study levels or intrinsic motivation vary in the learning paths and strategies they followed when using the adaptive e-learning material.

Chapter 9 summarizes the answers to the three central research questions and reflects on the methods that were used to perform the research. Students exploit all three adaptive features of Proteus: students differ in the number of exercises they need to finish adaptive e-learning material, they differ in the step sizes they choose and they read the tailored feedback that is part of the adaptive e-learning (Research question 1). We also observed a good effectiveness of the investigated adaptive e-learning material to provide students with different characteristics with a similar basic knowledge level (Research question 2). We investigated the relation between student characteristics and the learning paths and strategies they use when working with adaptive e-learning material and found that prior knowledge, study level and intrinsic motivation had an effect (Research question 3). We discussed the evaluation instrument that was used and the adaptive e-learning material that was created. This chapter concludes with the contributions that we have made to the practical information for teachers and to the scientific knowledge on the impact of student characteristics on their learning paths and strategies when using adaptive e-learning material.

In **Chapter 10** we suggest some future research topics that are interesting to look into following the research described in the thesis. We recommend looking to the effectiveness of the different types of feedback that is provided. In **Chapter 8** of the thesis, self-regulated learning by students is briefly explored. Since self-regulation is an important factor to successful learning, it is interesting to study this in more detail. Computer-based education such as the adaptive e-learning material investigated here provide useful information about the actions students undertake and offer a promising tool to study self-regulated learning. Proteus was initially developed to teach heterogeneous student groups resulting from a joint-degree program. The joint-degree program has ended, but the Bachelor-Master

system also increased student mobility and results increased heterogeneity of Master’s student groups. The use of adaptive e-learning therefore stays relevant. Recommendations to improve the adaptive e-learning system Proteus are given. The possibilities for adaptive e-learning material to teach heterogeneous groups both in traditional education and for distance learning are described. The chapter concludes with an outlook on the impact of the described studies for future research. In short, adaptive e-learning materials are suitable to teach heterogeneous student groups and provide a novel tool to investigate students’ (self-regulated) learning strategies.

Samenvatting

De verschillen in achtergrond van universitaire studenten zijn in de afgelopen jaren toegenomen door bijvoorbeeld de invoering van het Bachelor-Master stelsel. Dit stelsel maakt het voor studenten eenvoudiger om een studie in een ander land binnen Europa te volgen. De voorkennis van studenten die cursussen aan de universiteit volgen, kan daardoor behoorlijk uiteen lopen wat het lesgeven bemoeilijkt. Om de heterogene studentgroepen goed les te kunnen geven, is gepersonaliseerd onderwijs nodig. In gepersonaliseerd onderwijs wordt de leerstof op maat aangeboden en wordt ingespeeld op de leerbehoefte en leerstijl van de individuele student. Dit proefschrift evalueert een mogelijke manier om universitair biotechnologie onderwijs te personaliseren met behulp van adaptief digitaal lesmateriaal. Adaptief digitaal lesmateriaal ondersteunt docenten in het op maat aanbieden van theorie en oefeningen. De studie geeft informatie over óf en hoe adaptief digitaal materiaal werkt om heterogene studentgroepen op de universiteit te onderwijzen. We hadden daarbij zowel een praktische als wetenschappelijke doelstelling voor ogen. Het praktische doel was om docenten mogelijke oplossingen aan te reiken voor het personaliseren van hun onderwijs aan heterogene studentgroepen. Daarnaast wilden we een bijdrage aan de wetenschappelijke kennis over zelfregulerend leren leveren.

Hoofdstuk 2 geeft een overzicht van de bestaande literatuur over adaptief digitaal lesmateriaal. Adaptief digitaal lesmateriaal wordt gemaakt met adaptieve software systemen. Deze systemen bestaan uit meerdere componenten die het samen mogelijk maken om lesmateriaal op maat aan te bieden aan de individuele student. De componenten zijn: het inhoudsmodel, het student-model, het instructie-model en de adaptieve *engine*. Het adaptieve systeem, Proteus genaamd, dat is onderzocht in deze studie gebruikt student-gestuurde en systeem-gestuurde invoer om de instructie en feedback aan te bieden. Het kunnen sturen van het eigen leerproces (zelfregulerend leren) is volgens zowel leerpsychologen als beleidsmakers de sleutel tot succesvol leren op school en daarbuiten. Goede feedback versterkt het zelfregulerend leren door studenten. Het is daarom belangrijk om goede feedback te ontwerpen bij adaptief digitaal lesmateriaal. Er is nog weinig empirische onderzoek uitgevoerd naar zelfregulerend leren. Het onderzoeken van zelfregulerend leren met behulp van adaptief digitaal lesmateriaal is een veelbelovende methode, omdat de data worden verkregen in een natuurlijke setting, terwijl studenten werken met het adaptief digitaal lesmateriaal.

In **hoofdstuk 3** wordt het digitale leersysteem beschreven dat gebruikt is om het adaptieve digitale materiaal te maken: Proteus. Proteus varieert de hoeveelheid oefening en de inhoud van de feedback die de studenten krijgen. De aanpassing van de oefening en de feedback vindt plaats tijdens de interactie van de studenten met het digitale materiaal. De hoeveelheid training varieert om de leerbehoeften van studenten met weinig voorkennis te vervullen, maar studenten met meer voorkennis niet al te veel herhaling te geven. De inhoud van de feedback richt zich op specifieke fouten die studenten maken. Het systeem baseert het aantal oefeningen dat studenten krijgen aangeboden op het aantal fouten dat zij maken. Daarnaast kunnen studenten zelf vóór elke oefening een stapgrootte kiezen. Er zijn dus drie parameters die bijdragen tot aan de adaptiviteit van het systeem. Twee daarvan zijn systeem-gestuurd, namelijk (1) het aantal oefeningen dat gemaakt moet worden en (2) de presentatie van feedback. De andere is student-gestuurd, namelijk de keuze van de stapgrootte voor de volgende oefening.

Dit proefschrift geeft antwoord op de volgende drie centrale onderzoeksvragen:

1. Op welke manier personaliseert adaptief digitaal lesmateriaal, gemaakt met Proteus, instructie en hoe gebruiken en waarderen studenten deze adaptiviteit?
2. Hoe effectief is adaptief digitaal lesmateriaal, gemaakt met Proteus, in het verkrijgen van een basiskennisniveau binnen een heterogene groep studenten?
3. Welke kenmerken van studenten beïnvloeden hun leerpaden en -strategieën wanneer ze werken met adaptief digitaal lesmateriaal, gemaakt met Proteus?

Het onderzoek bestaat uit deelonderzoeken, waar evaluatief onderzoek is uitgevoerd tijdens het gebruik van verschillende adaptieve digitale modules. Deze deelonderzoeken zijn gerapporteerd in verschillende hoofdstukken. Elk hoofdstuk in dit proefschrift draagt bij aan beantwoording van één of meer van deze centrale onderzoeksvragen.

Hoofdstuk 4 beschrijft een nieuwe ontwikkelde methode om de oefeningen van adaptief digitaal materiaal, gemaakt met Proteus, op complexiteit in te delen. In plaats van de complexiteit te baseren op de ervaring van de docent hebben we drie niveaus van complexiteit uit de *Educational Taxonomy of Objectives* toegepast om leerdoelen met oplopende complexiteit te formuleren, namelijk onthouden, begrijpen en toepassen. Vervolgens hebben we adaptieve digitaal lesmateriaal voor PCR primer ontwerp (PCR tutor) ontwikkeld, waarbij de oefeningen van de verschillende leerdoelen passen binnen deze taxonomie. De indeling van oefeningen in de leerdoelen werd geverifieerd door een tweede wetenschapper. De leereffectiviteit van het aldus verkregen materiaal werd gemeten door een pre- en een post-test af te nemen bij meerdere groepen studenten op verschillende universiteiten. De PCR tutor was effectief in het onderwijzen van PCR primer ontwerp aan studenten met verschillende voorkennis. Het ontwikkelde materiaal is verder onderzocht in **hoofdstuk 8**.

Hoofdstuk 5 beschrijft het evaluatie-instrument, waarmee de variabelen om de drie onderzoeksvragen te beantwoorden gemeten worden. Het ontwikkeld instrument bestaat uit: (1) een pre- en post-test bestaande uit kennisvragen, (2) een vragenlijst die de mening en kenmerken van studenten meet en (3) digitale datasets van studenteninteracties met het adaptief digitaal lesmateriaal. De gebruikersinteracties die worden opgeslagen zijn: gekozen stapgrootte, de oefeningen die studenten krijgen, de antwoorden die ze geven en het aantal punten dat ze scoren. De betrouwbaarheid en validiteit van de attitudeschalen van de vragenlijst zijn gemeten en waren voldoende. De validiteit van de activiteitenrapporten werd geverifieerd door interviews met enkele deelnemers. De betrouwbaarheid van de pre- en post-test werd gemeten door antwoorden van studenten door een tweede corrector te laten nakijken en was goed. Het evaluatie-instrument is in de loop van dit onderzoek ontwikkeld. Dit betekent dat de beschreven evaluaties met steeds verder ontwikkelde versies van het evaluatie-instrument zijn uitgevoerd.

Hoofdstuk 6 evalueert het gebruik van adaptief digitaal materiaal over celgroeikinetiek: de CelGroei Kinetiek Tutor (CGKT). Het doel van deze tutor was studenten te voorzien van voldoendebasiskennis om de colleges over celgroeikinetiek te begrijpen en na de colleges het tentamen te kunnen halen. Drie student cohorten participeerden in het onderzoek. De groepen bestonden uit reguliere studenten met een Nederlandse vooropleiding en uitwisselingsstudenten, die deelnamen aan de cursus ‘Inleiding Proceskunde’ aan Wageningen University. De tentamenresultaten, vragenlijsten en gebruikersinteracties met het materiaal werden geanalyseerd om te onderzoeken of het materiaal het gewenste effect had. De resultaten suggereren dat studenten inderdaad verschillende leerpaden hebben gevolgd. Het verschil in tentamenresultaten tussen de reguliere en de uitwisselingsstudenten voor de introductie van de CGKT was groot. Dit verschil werd kleiner na de introductie van de CGKT en alle studenten presteerden gemiddeld beter. Over het algemeen waren de studenten positief over het gebruik van het materiaal. Wij concluderen daarom dat het gebruik van adaptief digitaal materiaal een goede manier is om verschillen in voorkennis van studenten die aan een cursus deelnemen aan te pakken.

Hoofdstuk 7 beschrijft de evaluatie van het ontwikkelde adaptieve digitale materiaal over enzymkinetiek: de Enzym Kinetiek Tutor (EKT). In deze studie hebben we onderzocht welke adaptieve kenmerken van de EKT werden gebruikt door een groep van 48 studenten levenswetenschappen. We hebben ook de waardering van studenten voor de EKT gemeten met behulp van het evaluatie-instrument (Hoofdstuk 5). Studenten zijn positief over het gebruik van de EKT en waarderen de adaptieve mogelijkheden. Onze bevindingen tonen ook aan dat instructies en feedback die de EKT aan individuele studenten presenteert, inderdaad varieert.

In **hoofdstuk 8** onderzochten we de invloed van individuele kenmerken van universitaire studenten op het gebruik van adaptief digitaal lesmateriaal, de PCR Tutor. We hebben de kenmerken van studenten in een heterogene groep bepaald door demografische gegevens te verzamelen en hun motivatie en voorkennis te meten met behulp van het evaluatie-instrument. We hebben ook de leerpaden die de studenten gevolgd hebben en hun gebruik van leerstrategieën tijdens het werken met de PCR-Tutor gemeten. Daarna combineerden we deze gegevens om te bestuderen of bepaalde kenmerken van studenten gecorreleerd zijn aan de gebruikte leerpaden en -strategieën. Onze bevindingen tonen aan dat geslacht geen effect had, maar dat studenten met verschillende voorkennis, in verschillende studiefase (bachelor of master) of met verschillende intrinsieke motivatie variëren in de leerpaden die zij volgden en leerstrategieën die zij kozen tijdens het werken met ede PCR Tutor.

Hoofdstuk 9 vat de antwoorden op de drie centrale onderzoeksvragen samen en reflecteert op de methoden die werden gebruikt om het onderzoek uit te voeren. Studenten benutten alle drie de adaptieve functies van Proteus: studenten verschillen in het aantal benodigde oefeningen om het adaptieve digitale lesmateriaal te voltooien, ze kiezen verschillende stapgroottes en ze lezen de op maat gemaakte feedback die deel uitmaakt van het adaptieve digitale lesmateriaal (onderzoeksvraag 1). We hebben ook gezien dat het onderzochte adaptieve digitale lesmateriaal effectief is om studenten met verschillende voorkennis te voorzien van een minimaal basiskennisniveau (onderzoeksvraag 2). We onderzochten de relatie tussen kenmerken van studenten en de leerpaden en -strategieën die ze gebruiken bij het werken met adaptief digitaal lesmateriaal. We vonden dat voorkennis, studieniveau en de intrinsieke motivatie een effect hadden op de gevolgde leerpaden en gekozen leerstrategieën (Onderzoeksvraag 3). Het hoofdstuk sluit af met reflecties op de praktische informatie voor universitaire docenten en de wetenschappelijke kennis over de impact van studentkenmerken op hun leerpaden en -strategieën bij het gebruik van adaptief digitaal lesmateriaal.

In **hoofdstuk 10** introduceren we toekomstige onderzoeksthema's naar aanleiding van het onderzoek dat beschreven is in dit proefschrift. We adviseren onderzoek te doen naar de effectiviteit van de verschillende soorten feedback. In hoofdstuk 8 van dit proefschrift is zelfregulerend leren door studenten kort onderzocht. Omdat zelfregulering een belangrijke factor voor succesvol leren is, is het interessant om deze studie in meer detail te herhalen. Computer-gebaseerd onderwijs, zoals het adaptieve digitale lesmateriaal dat hier onderzocht is, geeft nuttige informatie over de acties die studenten uitvoeren en biedt een veelbelovend instrument om zelfregulerend leren te onderzoeken. Proteus is in eerste instantie ontwikkeld om heterogene studentgroepen, ontstaan als gevolg van een joint-degree programma te onderwijzen. Het joint-degree programma is beëindigd, maar het Bachelor-Master stelsel veroorzaakt een toenemende mobiliteit van studenten. Het gebruik van adaptieve digitaal lesmateriaal blijft dan ook relevant. Verder geeft dit hoofdstuk aanbevelingen om het adaptieve digitale onderwijssysteem Proteus te verbeteren. De mogelijkheden om adaptief digitaal lesmateriaal zowel in het traditionele onderwijs als voor afstandsonderwijs te gebruiken, worden beschreven. Het hoofdstuk wordt afgesloten met een kijk op de impact van de beschreven studies voor toekomstig onderzoek. Al met al kan adaptief digitaal lesmateriaal geschikt zijn voor het onderwijzen van heterogene groepen studenten en biedt het een nieuw hulpmiddel om (zelfregulerende) leerstrategieën van studenten te onderzoeken.

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Curriculum Vitae

Janneke (Johanna Rosemarie) van Seters was born the 11th of November 1981 in Vlaardingen. She completed her secondary education (gymnasium) at SG Spieringshoek in Schiedam in 2000. In the same year she started her BSc study Molecular Sciences at Wageningen University. She obtained her propedeuse in 2001 and her BSc degree in 2004. She continued the master program Molecular Sciences with the specialization of Biological Chemistry. In 2006 she graduated and started to work at both the Education Institute and the section Corporate Communication of Wageningen UR. In 2007 she continued her work at the department of Process Engineering of Wageningen UR as project leader for B-Basic. In 2008 she started her part-time PhD research on the evaluation of adaptive e-learning for biotechnology of which the results are described in this thesis. In 2011 she started her current job of policy employee at the section Corporate Governance and Legal Services of Wageningen UR.

Janneke (Johanna Rosemarie) van Seters werd op 11 november 2011 geboren in Vlaardingen. Zij behaalde in 2000 haar gymnasium diploma aan SG Spieringshoek. In datzelfde jaar begon zij met haar studie Moleculaire Wetenschappen aan Wageningen Universiteit. Ze behaalde haar propedeuse in 2001 en haar BSc diploma in 2004. Ze vervolgde haar MSc programma met de specialisatie Biologische Chemie. In 2006 behaalde zij haar MSc diploma en begon met haar werkzaamheden bij de afdeling Corporate Communication van Wageningen UR. In 2007 vervolgde ze haar werkzaamheden bij de leerstoelgroep Bioprocestechnologie van Wageningen UR als projectleider van het onderwijsprogramma van B-Basic. In 2008 startte zij daarnaast een parttime promotieonderzoek op het gebied van adaptief digital lesmateriaal voor biotechnologie. De resultaten daarvan zijn in dit proefschrift beschreven. In 2011 begon ze met haar huidige baan als beleidsmedewerker bij de afdeling Corporate Governance & Legal Services van Wageningen UR.

List of publications

Publications in peer reviewed journals based on this study

Van Seters, J.R., Ossevoort, M.A., Goedhart, M.J., & Tramper, J. (2011) *Accommodating the difference in students' prior knowledge of cell growth kinetics*. Electronic Journal of Biotechnology. **14**(2) http://dx.doi.org/210.2225/vol14-issue2-fulltext-2

Van Seters, J.R., Lanfermeijer, F.C., Van der Schaaf, H., Tramper, J. Goedhart, M.J. & Ossevoort, M.A. *A Web-Based Adaptive Tutor for Enzyme Kinetics*, Journal of Chemical Education. (*under review*)

Van Seters, J.R., Wellink, J., Tramper, J., Goedhart, M.J. & Ossevoort, M.A. (2011). *A Web-Based Adaptive Tutor to Teach PCR Primer Design*. Biochemistry and Molecular Biology Education. http://dx.doi.org/10.1002/bmb20563

Van Seters, J.R., Ossevoort, M.A., Tramper, J., & Goedhart, M.J. (2011) *The influence of student characteristics on the use of adaptive e-learning material.* Computers & Education. http://dx.doi.org/10.1016/j.compedu.2011.11.002

Contributions to scientific conferences

Van Seters, J. R., Sessink, O. D. T., Hartog, R. J. M., & Tramper, J. (2008). *Influence of Adaptive Digital Learning Material On Learning Effectiveness of Individual Students.* Paper presented at INTED Conference, Valencia, Spain.

Van Seters, J., Lanfermeijer, F., van der Schaaf, H., Ossevoort, M., Goedhart, M., & Tramper, J. (2009). *Development and Evaluation of an Adaptive Digital Module on Enzyme Kinetics*. Paper presented at E-Learn conference, Vancouver, Canada.

Van Seters, Janneke; Ossevoort, Miriam; Tramper, Hans & Goedhart, Martin (2010) *Evaluatie van adaptief digitaal leermateriaal voor biotechnologie in universitair onderwijs*. Paper presented at the ORD, Enschede, The Netherlands

Van Seters Janneke, Ossevoort Miriam, Tramper Johannes , Goedhart Martin (2011) *Use of an adaptive digital module for molecular biology by students with varying prior knowledge*. Paper presented at ESERA Conference, Lyon, France.

Other publications in peer reviewed journals

Bicanic, D., Westra, E., Seters, J., Van Houten, S., Huberts, D., Colic-Baric, I., et al. (2005). *Photoacoustic and optothermal studies of tomato ketchup adulterated by the red beet (Beta vulgaris)*. Journal De Physique. IV : JP, 125, 807-810.

Van Seters, J.R., Sijbers, J.; Denis, M.; Tramper, J. *Build your own second-generation bioethanol plant in the classroom!* (2010) Journal of Chemical Education, **88** (2), 195-196. http://dx.doi.org/10.1021/ed100791w

Other publications

Holtslag, F., Kessel, T. v., Velden, T. v. d., Kuipers, R., Seters, J. v., & Lorier, J. (2008). *Bioinformatica 'DNA on a string', de bits & bytes van de erfelijke code* (1.0 ed.). Wageningen: Stichting Leerplan Ontwikkeling.

Linssen, G., Koeneman, M., Tramper, J., & Seters, J. R. v. (2009). *Food or Fuel?, Bio-ethanolproductie uit cellulose-afval*. Wageningen.

Overview of completed training activities

Conferences

NLT conference	2007, 2008, 2010#
Serious gaming, serious simulation	2007
B-Basic Symposium	2007, 2008#*, 2009#, 2010#
INTED	2008#
Het gebruik van vragenlijsten in Survey onderzoek	2009
NLT Nascholing	2009#
E-Learn	2009#
Biologie Onderwijsconferentie	2010#
BE-Basic symposium	2010#
Workshop on environmental, social and economic impacts of biofuels	2010
ESERA Conference	2011#

 # Oral presentation ** Poster presentation*

Discipline specific courses

Uitdagende leertaken en studiehandleidingen maken	2007
Advanced Course Vizualisation Cellular Processes	2008#

 # Oral presentation

General courses

Workshop projectmanagement	2007
Afstudeervak begeleiden en organiseren	2007
Information Literacy, including Introduction Endnote	2008
Endnote Advanced	2008
Scientific writing	2011
Career perspectives	2011

Optionals

Preparation of research proposal	2007
PhD Trip Process Engineering to Japan	2008
Digital learning meetings	2009-2011
Industriële begeleidingscommissie biotechnologie-opleiding	2008, 2010
WU Sprint overleg	2007-2010
Participation DUDOC course program	2008-2011

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Figure 1 made by www.bartdepiraat.nl
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